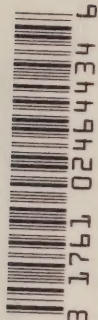


CA1 EP 93R26

Canada. DOE. State of the Environment Reporting.
RESULTS OF REGIONAL WORKSHOPS ON ECOLOGICAL MONITORING
AND INDICATORS. / Stacier, Cynthia; Freedman, Bill;
Shackell, Nancy 1993.

CA 1 EP93R26



Results of Regional Workshops on Ecological Monitoring and Indicators

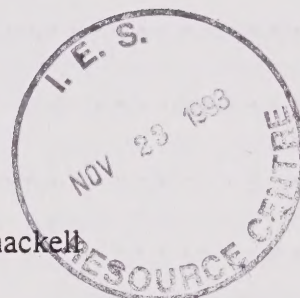
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Prepared for State of the Environment
Reporting Organization, Environment Canada
Contracts KA171-1-5384
KA171-1-7874

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EXECUTIVE SUMMARY

In 1991, SOER asked a group of ecologists at Dalhousie University to develop a conceptual framework for a National Ecological-Monitoring Program for Canada. After this framework was developed, SOER asked Dalhousie University to convene a series of workshops to obtain regional feedback on the proposed framework. The discussion document "*A Framework for a National Ecological-Monitoring Program*" served as a basis for the regional workshops on ecological-monitoring and indicator development.

The objectives of each workshop were to: (1) review and comment upon the proposed framework; (2) identify regional stressors considered to be actually or potentially important in the ecozone(s) within each region; (3) identify existing sources of information relevant to monitoring, and evaluate the information for the purposes of state-of-the-environment reporting; (4) identify deficiencies in the available information and suggest indicators to address those deficiencies; and (5) engage in a broad discussion of monitoring, indicators of environmental quality and ecological integrity, and other issues related to state-of-the-environment reporting.

Workshops were convened for 1.5 days in the Atlantic, Pacific, Northern, and Prairie Regions of Canada. In addition, a series of informal discussions on ecological monitoring were held at several places in the Ontario Region, and a consultation-workshop was held in the Quebec Region. Although the goals of each workshop were similar, the workshop structure remained flexible to meet the needs of each group of participants. As a consequence, the product of each workshop was unique and reflected the expertise, experience, interests, and concerns of the participants. The results of each workshop or meeting were summarized in an individual report, and suggestions regarding the proposed framework were incorporated into successive revisions of the discussion document. This information has been synthesized within two summary documents:

- (1) The present document includes information regarding: (a) identification of stressors affecting particular regions of Canada; (b) proposed indicators suitable for monitoring the effects of these stressors; and (c) discussions of existing monitoring programs, or sites that could serve as part of a network of intensive-monitoring sites.
- (2) A companion document (Freedman *et al.* 1993) describes the conceptual framework of the proposed national monitoring program and includes the participants' comments that were specific to the conceptual or functional design of the proposed program.

The present document, "*Results of Regional Workshops on Ecological Monitoring and Indicators*" summarizes information from the workshops that is mainly region-specific or stressor-specific. Of particular note are assessments of the importance of different stressors to different ecozones or ecosystems, and also lists of potential indicators specific to particular stressors. This information may be useful in the establishment, development, and integration of monitoring programs at the regional or national scale. A major deficiency identified for existing regional or national monitoring programs was the general lack of data on biological responses to important environmental stressors.

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INTRODUCTION

The ultimate goal of environmental monitoring is to avoid a deterioration of ecological integrity, or more broadly, of environmental quality. This objective is based on the premise that healthy ecosystems are required to sustain our society and our economic development.

The State of the Environment Reporting Organization (SOER) of Environment Canada periodically reports on aspects of environmental quality in the different regions of Canada. The broad objectives of state-of-the-environment monitoring are to: (1) detect changes in environmental conditions on regional and/or national scales; (2) develop regional- and/or national-scale indicators of environmental quality; (3) predict future changes; and (4) interpret the likely consequences of change. To enhance its capabilities, SOER is now part of an integrated, national-scale, monitoring and reporting network.

In 1991 SOER asked a group of ecologists at Dalhousie University to develop a conceptual framework for a National Ecological Monitoring Program for Canada. A basic conceptual framework was developed, aided by library research and discussions with professionals, and was outlined in a discussion document. SOER then asked Dalhousie University to convene a series of regional workshops to obtain feedback on the proposed framework. The discussion document "*A Framework for a National Ecological-Monitoring Program*" was used as a basis for a series of regional workshops on ecological monitoring and indicator development. After each workshop, the discussion document was modified based on the comments of participants.

The results of each workshop have been summarized in the individual workshop reports, which have been distributed to the participants of the respective workshops. Subsequently the information in the individual workshop reports has been synthesized within two summary documents:

- (1) The present document includes information regarding: (a) identification of stressors affecting particular regions of Canada; (b) proposed indicators suitable for monitoring the effects of these stressors; and (c) discussions of existing monitoring programs, or sites that could serve as part of a network of intensive-monitoring sites.
- (2) A companion document (Freedman *et al.* 1993) describes the conceptual framework of the proposed national monitoring program and includes the participants' comments that were specific to the conceptual or functional design of the proposed program. A synopsis of the companion document is presented in the next section of the present report.

The present document serves to summarize information from the workshops that is mainly region-specific or stressor-specific. Of particular note are assessments of the importance of different stressors to different ecozones or ecosystems, and also lists of potential indicators specific to particular stressors. This information may be useful to various persons involved in the establishment, development, and integration of monitoring programs at the regional or national scale.

The reader should note that, although the goals of the workshops were similar, each was a unique experience. The product of each workshop reflects the expertise, experience, interests, and concerns of the participants. Organizers of the workshops attempted to tailor each to the needs of the participants by offering a flexible structure to the meetings. As a result, this summary document may be less balanced and cohesive than might be desirable. However, this document does accurately reflect the results of the different workshops.

In this report, information has been integrated across the workshops to the extent possible. The organization is as follows: (1) an overview of each workshop is presented; (2) examples of intensive-monitoring sites and programs are discussed; (3) regional stressors are listed and discussed; (4) ecological-indicators that are appropriate for different regional stressors are listed and their availability evaluated; and (5) names of the participants in each workshop are provided.

SYNOPSIS OF THE PROPOSED FRAMEWORK FOR A NATIONAL ECOLOGICAL-MONITORING PROGRAM

The **conceptual design** of the program is intended to integrate **monitoring and research** at the national level. Indicators would be measured at **two classes of monitoring sites (intensive and extensive)** in each of the **15 terrestrial ecozones** of Canada. Within ecozones, potential indicators relevant to the most important regional concerns/issues would be identified. Indicators would be evaluated by expert working groups, and a suite of appropriate indicators would be chosen to monitor for changes in environmental quality at the regional or national scale. Measurement of indicators would be integrated within and among extensive and intensive-monitoring sites.

Intensive-monitoring sites would be used for relatively detailed monitoring of indicators relevant to structural and functional ecology, and their responses to environmental change. Intensive-monitoring sites would include: (1) **reference sites**, located in ecological reserves or other protected areas, and used for the study of ecosystem structure and function, and for monitoring the effects of regional and global change, (2) **experimental sites**, where environmental stressors are manipulated under controlled conditions and the ecological responses are studied, and (3) **stress-gradients**, consisting of a series of sites representing a gradient with respect to a particular anthropogenic stressor, such as agriculture or forestry. A total of 1-3 intensive sites is suggested for eventual development in each ecozone, depending on its size, biogeophysical heterogeneity, and suite of important environmental stressors.

The national network of intensive-monitoring sites should capitalize on on-going programs of ecological monitoring and research. However, the new network must deal with deficiencies in the existing programs, including: (1) a lack of intensive sites in some ecozones, and (2) insufficient integration of atmospheric, aquatic, and terrestrial components, and (3) a general paucity of standardized biological indicators.

Extensive-monitoring sites would be more numerous and located throughout each ecozone to gain an overview of larger-scale changes in the ecological character of the landscape. In all ecozones, much extensive-monitoring data are presently available from existing programs of co-operating sectoral agencies. However, there are two important deficiencies with the existing information: (1) biological-response indicators are particularly deficient, yet these are the most relevant indicators of ecological integrity; and (2) the spatial designs of current sectoral-monitoring programs often do not provide data that are statistically-representative of regions or ecozones.

Initial steps in the proposed framework are to: (1) identify major sources of environmental stress in particular ecozones; (2) identify deficiencies in the available indicators of environmental quality; and (3) develop protocols for the selection of ecological indicators and evaluation of data quality.

Monitoring programs should be institutionalized within government, and should be integrated with research programs. Related ecological research could be conducted by government and non-government (e.g., university and private sector) scientists. The role of research should include: (1) the development of indicators, (2) hypothesis-testing relevant to the causes and consequences of environmental change, (3) determination of the compatibility of monitoring techniques, and (4) multi-disciplinary study of structural and functional ecology.

For **national reporting**, the State of the Environment Reporting Organization of Environment Canada (SOER) relies on data collected by other institutions. SOER does not have the capability to conduct monitoring activities, nor is one planned. The role of SOER in the proposed program would be to: (1) coordinate and assist working groups comprised of experts from government and non-government agencies, and the regions of Canada, to undertake various activities (see below); (2) catalog and evaluate existing databases for use in state-of-the-environment reporting; (3) request, obtain, and maintain data for use in state-of-the-environment reports; (4) coordinate, integrate, map, and analyze the data for the purposes of state-of-the-environment reporting; (5) prepare reports, fact-sheets, and other products that document the state of the environment, and where possible, forecast environmental trends; (6) facilitate partnerships with and among sectoral agencies; (7) coordinate a national network of ecological-monitoring sites; (8) catalog and maintain a monitoring database that will be accessible to other agencies and the public; and (9) identify deficiencies in national ecological monitoring and relevant research, and make recommendations to address these deficiencies.

Expert working groups are important in the proposed framework, and would assist SOER in some of the functions described above by: (1) identifying the most important sources of environmental stress in particular ecozones; (2) suggesting suitable indicators to monitor for the effects of the stressors; (3) identifying deficiencies in the available environmental database that relate to the effects of these stressors, and recommending modifications to sectoral-monitoring programs to address those deficiencies; (4) identifying deficiencies in the development of suitable indicators, and directing the development of protocols for the selection and measurement of ecological indicators; (5) directing research to establish protocols for the comparison of different techniques and the evaluation of data quality; and (6) interpreting trends in indicators and suggesting causal hypotheses.

Important concerns identified during the workshops include the following: (1) financial considerations, including funding requirements and increasing cost-effectiveness; (2) fostering cooperation among government agencies, and encouraging partnerships with the academic scientific community, the aboriginal community, and volunteers; (3) suggestions regarding the process of data acquisition by SOER, including accessibility of data, benefits to data contributors, and types of information requested; (4) future directions in monitoring and research programs, including issues related to measurements, mandates, adaptability of programs, sample archives, monitoring for unknown stressors, composite indices, and development of biological-response indicators (the latter are especially deficient in current monitoring programs); (5) issues related to state-of-the-environment reporting units; and (6) transfer of information to the public, including notions of environmental quality, interpretation of environmental change, and environmental education in the broad sense.

Wherever possible, the proposed program would build upon existing capabilities and expertise for ecological monitoring and research. Existing programs would be evaluated with respect to providing appropriate information for a national network of ecological-monitoring sites. Deficiencies in existing programs would be addressed by integrating present networks and by establishing new sites where necessary. The success of the program would depend upon the cooperation of all agencies that are involved in relevant monitoring activities, and the development of partnerships with research groups.

WORKSHOP AGENDA

Workshops were convened for 1.5 days in the Atlantic, Pacific, Northern, and Prairie Regions of Canada. Participants in each workshop were asked to review a draft document entitled: "*A Framework for a National Ecological-Monitoring Program.*" That document outlined a conceptual framework for a national monitoring program, and provided background for the workshop discussions.

The objectives of each workshop were to:

- (1) review and comment upon the proposed "*Framework for a National Ecological-Monitoring Program;*"
- (2) identify regional stressors considered to be actually or potentially important in the ecozone(s) within each region;
- (3) identify existing sources of information relevant to monitoring, and evaluate the information for the purposes of state-of-the-environment reporting;
- (4) identify deficiencies in the available information and suggest indicators to address those deficiencies; and

(5) engage in a broad discussion of monitoring, indicators of environmental quality and ecological integrity, and other issues related to state-of-the-environment reporting.

Time constraints did not permit a truly comprehensive approach to these tasks at each workshop. Among the various workshops, however, most nationally-important stressors were identified and relevant indicators were developed. In addition, several intensive-monitoring programs were developed to deal with regional stressors.

In addition to the four workshops that followed the agenda described above, a series of informal discussions on ecological monitoring were held at several places in Ontario Region, and a consultation-workshop was held in Quebec Region.

WORKSHOP SUMMARIES

In this section, the results of the workshops or consultations meetings in each region are briefly summarized. Later sections provide more detailed information on intensive-monitoring sites and programs, regional stressors, and ecological-indicators for extensive-monitoring.

Atlantic Region

The first regional workshop was convened in Halifax in February 1991. The purpose of this workshop was to discuss ecological monitoring and indicators, and to identify issues and concerns within the Atlantic Region administrative unit of Environment Canada. Most of the 35 participants were government scientists involved in environmental research and/or monitoring in the Maritime region. The objectives of the workshop were to: (1) discuss the regionalization of environmental data pertinent to state-of-the-environment (SOER) reporting, and (2) identify important gaps in the available information.

Workshop participants were divided into three groups. Two groups discussed regional indicators measured at extensive-monitoring sites. The third group discussed potential and existing monitoring programs at Kejimikujik National Park, as an example of an intensive-monitoring site in the Atlantic Maritime ecozone.

The use of the processes outlined in the discussion document "*A Framework for a National Ecological-Monitoring Program*" was illustrated by workshop exercises. The process of selecting indicators for monitoring was guided by identification of the main stressors pertinent to the Atlantic Maritime ecozone. Matrices of stressor (horizontal) by exposure and response indicators (vertical) were prepared for extensive- and intensive-monitoring sites, based on the workshop results and the expertise of the participants. In addition, the availability of indicators was evaluated.

Issues relevant to the proposed framework were discussed, with the following results:

- (1) Participants largely agreed that a large amount of information relevant to SOER is available, though primarily for extensive (or sectoral) monitoring.
- (2) An initial step in the design of an ecological-monitoring program should be the identification of existing data appropriate for SOER reporting. Evaluation of the quality of the data should include whether they can be used to represent the region.
- (3) An important impediment to SOER reporting will be the difficult task of coordinating and assessing data from different agencies.
- (4) There is an important lack of data relevant to non-economic wildlife species (wildlife refers to any plant or animal life other than humans).

Pacific Region

The second regional workshop was convened in Vancouver in June 1991. The 38 participants included representatives from provincial and federal agencies, the private sector, and universities. Participants were divided into three discussion groups, two of which discussed extensive-monitoring and one discussed intensive-monitoring programs. Stressors identified as being particularly important to B.C. were related to marine activities and forestry. Workshop participants discussed these stressors in detail and developed lists of indicators considered suitable for monitoring for the effects of those stressors.

Recommendations and concerns for a national monitoring program included the following:

- (1) Intensive ecosystem studies could be conducted along an operational or experimental stress-gradient of sites, classified according to successional stage and/or disturbance regime (e.g., mining, forestry, or agriculture). Such intensive sites would facilitate setting "ecological integrity" objectives for managerial purposes.
- (2) Criteria for selection of indicators should be developed in the revised framework.
- (3) A protocol is needed to evaluate the quality of source data for SOER reporting.
- (4) The great biophysiographic variability of B.C. is not adequately reflected within the federal scheme of 15 terrestrial ecozones. Participants were concerned about use of a limited number of ecozones for reporting purposes.
- (5) The spatial and temporal design of current monitoring programs imposes constraints on SOER reporting. Statistical inferences for a region can only be made if sampling stations are appropriately chosen, from a probability sample, to represent that region. Otherwise, results cannot be generalized beyond the sample population. Furthermore, if different spatial and temporal scales are used for sampling different indicators, it will be difficult to identify causal links between stressors and responses, let alone integrate measurements on a regional scale.

- (6) When environmental changes are detected and perceived to be detrimental, then remedial measures can be recommended, even though most indicators have not been studied thoroughly enough to set management objectives (e.g., nutrient status of forest or agricultural soils).
- (7) Two issues to be addressed in the revised framework are: (a) monitoring for-the-sake-of monitoring vs. question-oriented monitoring, and (b) the integration of monitoring and research.
- (8) The monitoring programs of different agencies should be integrated through all stages of a long-term monitoring program, from design through to the interpretation of data. This integration is obviously a difficult task. Perhaps SOER could provide a central administrative structure, to ease and facilitate coordination among provincial, federal, and non-governmental monitoring agencies.

Northern Region

The third regional workshop was convened in Yellowknife, in February, 1992. The 26 participants and 23 correspondents included scientists, research directors, and policy analysts from territorial and federal agencies, and from universities.

Participants first prepared a list of stressors that affect the Northwest Territories, and then formed two discussion groups to focus on different categories of stressors. Stressors examined by Group 1 were long-range transported pollutants, stratospheric ozone and UV-b, and climate change. Group 1 developed matrices of exposure and response indicators for extensive- and intensive-monitoring of these stressors. Group 2 examined stressors that were more directly related to human activity in the Northern Region. These stressors included resource development (minerals, oil, and gas), wildlife exploitation (hunting, fishing, and trapping), human population growth, and tourism. Group 2 developed lists of indicators for extensive-monitoring of these stressors, and discussed intensive-monitoring, including criteria for the selection of sites and design of programs.

Following these activities, each group presented its results to the other workshop participants. A general discussion ensued and focused on the following topics: identification of stressors and evaluation of indicators; the order of steps in the proposed framework; concerns of Northern Region relevant to national SOE reporting; the logistics of developing a national ecological-monitoring program; fostering partnerships; and various potential roles of SOER.

As a result of the Yellowknife workshop, the following modifications were made to the framework document: (1) The order of certain steps in the process was changed (Figure 3 in Freedman *et al.* 1993). Notably, cataloguing the databases is a primary step, but one that can occur in parallel with identification of important stressors. (2) The potential problems associated with using terrestrial ecozones as the basis for reporting were discussed more thoroughly. (3) Regional concerns with respect to national monitoring and reporting were addressed in more detail. (4) The logistics involved in the proposed national program were more thoroughly discussed, including the roles of SOER and expert working groups in both

monitoring and reporting. It was noted that the latter includes environmental education in the broader sense. (5) A brief comparison between the proposed framework and EMAP (the U.S. national monitoring system) was included.

Prairie Region

The fourth workshop (Prairie Region) was held in Winnipeg, in February, 1992. The 34 participants and 32 correspondents included scientists, administrators, and policy analysts from territorial and federal agencies, and from universities. Participants prepared a list of stressors affecting the prairie provinces, and formed three working groups to discuss aspects of environmental monitoring in Prairie Region. Although included in the Prairie administrative unit, forest habitats were not discussed in detail in this workshop; the focus was on prairie habitats, because these were not addressed in other regional workshops.

Group 1 focused on extensive-monitoring of the intensity and effects of stressors on agricultural ecosystems, and also discussed designs for intensive, ecological monitoring of these systems. Group 2 focused on extensive-monitoring of the intensity and effects of stressors on aquatic ecosystems. Each group assessed the relative importance of different stressors on different ecosystems, and developed lists of indicators that could be used to monitor the regional effects of the selected, more-important stressors. Group 3 focused on intensive-monitoring, and developed a program for monitoring the ecological effects of climate change. Because of its history of integrated, longer-term ecological research and monitoring, the Experimental Lakes Area (ELA) was highlighted as a candidate intensive-monitoring site. Although ELA is in a boreal forest region, stressors and indicators specific to terrestrial ecosystems were not addressed, due to time constraints. Most discussion of ELA focused on aquatic indicators, a fact that largely reflected the expertise of the participants in the group.

Following these activities, the groups presented their results to the other workshop participants. A general discussion ensued and focused on these topics: concerns of Prairie Region relevant to national SOE reporting; identification of stressors and evaluation of indicators; interpretation of environmental data; environmental education; the logistics of developing a national ecological-monitoring program; timing of the cycle of the national SOE report; data acquisition and use; cooperation among agencies; and various potential roles of SOER.

As a result of the Winnipeg workshop, the following modifications were made to the framework document: (1) Regional concerns with respect to national monitoring and reporting were addressed in more detail. (2) The roles of SOER and expert working groups in both monitoring and reporting were discussed in more detail. (3) It was noted that reporting includes environmental education. (4) The logistics involved in the proposed national program were addressed, including data acquisition, spatial and temporal coordination of monitoring activities, and facilitation of networks. (5) The conceptual model for stressors and indicators was refined, and a stressor-gradient model was developed.

Ontario Region

Several shorter meetings were held in Ontario in March 1992 for the purpose of obtaining regional commentary on the proposed framework for a national ecological-monitoring program. Because of time limitations, some of the general workshop objectives could not be addressed in the Ontario meetings. Specifically, we were unable to engage in the day-long exercises in which lists of regionally-important stressors and indicators were identified. Instead we focused on obtaining feedback on the conceptual and functional design of the proposed framework for an ecological-monitoring program.

In these meetings three broad viewpoints were represented through four separate consultations: (1) Ontario government research scientists (Dorset Research Centre, Ministry of the Environment, Water Resources Branch); (2) the academic research community (Institute for Environment and Resource Studies, Trent University; Institute for Environmental Studies, University of Toronto); and (3) Ontario government persons involved in various aspects of regional environmental monitoring, including administration, program design, field sampling, laboratory analysis, and research (Ministry of the Environment, Air Resources Branch, Toronto).

The results of the Ontario meetings were summarized in a separate report. Most of the commentary related to the general design and implementation of the proposed program, and these comments have been used to revise the framework. Information relevant to intensive-monitoring programs are included in the present document.

Quebec Region

The fifth regional consultation was held in Montreal in June 1992. This consultation was organized by Environment Canada, because the participants from Dalhousie University are unilingual Anglophones. The discussion considered emerging ecological-monitoring initiatives in a broader sense, and did not focus solely on the Dalhousie framework for a national ecological-monitoring program. This present summary is based in large part on minutes of the meeting prepared by Alain Bernier, modified by the authors.

The meeting began with a presentation by Bill Freedman, in which the draft framework for a national ecological-monitoring program was described. The Dalhousie framework proposes a national ecological-monitoring network, with intensive- and extensive-monitoring sites, and a process for the identification of environmental indicators. These various concepts influenced much of the discussion during the Quebec present workshop on ecological monitoring.

The next presentation, by Christian Pupp of SOER, gave an overview of a national workshop on ecological monitoring held in Toronto in May 1992. He drew a link between this initiative, the Green Plan, and Environment Canada's Transition Team. Two task groups in Environment Canada are examining various aspects of the integration of national monitoring networks and of integrated ecological monitoring. The format of the national program that eventually emerges is impossible to predict, but it would be reasonable to expect that Quebec Region would have one or two sites for intensive ecological monitoring.

In the ensuing discussion, participants noted that budget cuts likely will increase, and that some responsibilities relevant to environmental monitoring may be transferred to the provinces. The provincial government of Quebec, which was not represented in this workshop, is obviously a key player in ecological monitoring. In all jurisdictions of Canada there have always been overlap and duplication among the monitoring programs of the various levels of government.

Initial priorities for Quebec Region should include the following:

- (1) Establishment of a regional consultation committee to encourage the exchange of information and co-operation amongst partners in (a) an integration of environmental monitoring and (b) the establishment of an ecological-monitoring program. A key role of the committee would be to strike a working group to inventory and analyze existing monitoring programs.
- (2) Analysis of mechanisms that would make monitoring data more readily available;
- (3) Development of a process to integrate ecological-monitoring activities in Quebec, including activities of the provincial government, industry, and non-government organizations, as well as the federal government;
- (4) Development of innovative, cost-effective ways to run monitoring programs, perhaps including the involvement of volunteers in the operation of networks;
- (5) Production of national guidelines and protocols for the development of networks and indicators, and development of capability and expertise in the regions to implement the system;
- (6) Refinement of the concept of an integrated, ecological-monitoring network. Such a network will require the integration of new and existing sites. It is also important that indicator data be integrated; and
- (7) Implementation, as soon as possible, of national and regional projects to demonstrate the effective integration of ecological monitoring.

Discussion during the workshop noted that the role of the SOER team must be clarified. Should SOER be involved in all initiatives? The needs and mandate of SOER do not cover all initiatives, and SOER does not have the resources to manage all activities in a comprehensive ecological-monitoring program. Furthermore, because the national and SOER needs and mandates are not the same as regional needs, the objectives of a "national" ecological-monitoring network will have to be broad enough to encompass "regional" objectives.

With respect to environmental management, the monitoring network should be adaptive, with sufficient flexibility to change over time to reflect emerging priorities. It was noted that indicators of the effectiveness of environmental management could distort a program of ecological monitoring and reporting. Compared with many ecological indicators,

environmental-management indicators serve particular, management-oriented purposes, may use different sites, and are designed to allow simple and direct interpretation.

It was agreed that the monitoring of stressor and exposure indicators should be balanced by the monitoring of a sufficient number of indicators of environmental quality, including ecological-response indicators.

Other comments relevant to a national ecological-monitoring program included the following:

- (1) Political barriers to integrated activities are an important concern everywhere, but especially in Quebec. This is a very important consideration which must be dealt with during the development of an operational program of integrated monitoring in Canada. To illustrate this point, it was frequently lamented that the present constitutional uncertainties in Canada have resulted in a lack of representation of agencies of the Province of Quebec at the present workshop.
- (2) The ecozone framework does not have to be exclusive. For example, the St. Lawrence basin provides a sensible eco-geographic focus, and would be a valuable unit, at least for reporting purposes.
- (3) The specific role of SOER in the development, co-ordination, and implementation of a national ecological-monitoring program must be clarified.
- (4) The present consultation in Quebec Region is strongly focused on Environment Canada, and consequently is not as broadly based as is desirable. Prospective partners that were specifically identified as not (or insufficiently) represented at the present meeting were: (a) the Provincial Government, most notably Quebec Departments of the Environment, Forestry, and Agriculture, Fisheries and Food; (b) Energy, Mines and Resources Canada, (c) the Canadian Space Agency; (d) universities and non-government research centres; (e) the private sector; and (f) non-government organizations with an interest in environmental quality and environmental monitoring.
- (5) It will be important that citizens understand the purpose and nature of the ecological-monitoring program, and its relevance to the identification, quantification, and resolution of important environmental problems. This issue will be especially important for intensive-monitoring sites and networks.

INTENSIVE-MONITORING SITES AND PROGRAMS

Introduction

Participants in all of the regional workshops discussed various aspects of intensive-monitoring. In this section we present some of the highlights of these discussions. Included are lists and discussions of existing and potential intensive-monitoring sites and programs, a few 'case studies' of existing or possible programs, criteria for selection of intensive-monitoring sites, and various lists of stressors and ecological-indicators relevant to intensive-monitoring in some of the ecozones.

The suggested locations of intensive-monitoring sites include greater-national parks (that is, national parks plus their surrounding, peripheral area) and other types of ecological reserves, as well as established research areas. Examples of such locations were discussed in all regional workshops. For a number of such candidate sites, intensive-monitoring programs were developed. The results of these discussions are summarized below.

National Parks

For several reasons, National Parks and their peripheral areas would be suitable sites for the intensive-monitoring of ecological indicators and integrated ecological research. Obvious reasons for using parks as monitoring sites are their accessibility and on-site facilities, which can accommodate personnel and equipment required for monitoring and research activities. Other reasons for establishing sites in parks are discussed below.

As an agency, the Parks Service has a history of using an integrated approach to management. The goals of the Parks Service are diverse, and include protection of ecological heritage, interpreting resource values to the public, and monitoring environmental quality and user satisfaction. Furthermore, there is much interest among park staff to be involved in monitoring indicators relevant to ecological integrity.

With regard to monitoring, the Parks Service has more flexibility in terms of mandate than other agencies. The Parks Service is currently being restructured, according to Green Plan directives. Some funds are being redirected, for example from infrastructure (e.g. road and building maintenance) to research and monitoring. These fundamental changes reflect the increasingly pro-active approach of the Canadian Parks Service with respect to environmental and management issues.

In addition, the Parks Service recognizes that the ecological integrity of national parks can be significantly challenged by resource-management activities occurring in their surrounding, peripheral areas. Recognition that a national park plus its peripheral area comprise an integrated landscape, allows for a ready acceptance of an integrated design of intensive-monitoring sites. In such a design, the national park would be used for reference monitoring

and research, while in the adjacent area, monitoring and experimental research on important stressors (e.g., whole-lake acidification, watershed logging, agricultural activity, etc.) can be conducted.

During several workshops we developed frameworks for integrated-monitoring programs focusing on several national parks plus their peripheral areas. Here we present summaries of these frameworks, for Kejimikujik National Park in Nova Scotia, Elk Island National Park in Alberta, and Yoho National Park in British Columbia.

Elk Island National Park is located west of Edmonton, at the junction of three major ecosystem types -- grassland, boreal forest, and aspen parkland. The distributions of these habitats are sensitive to changes in climate, which makes the park useful for monitoring ecological changes caused by climate change. Changes in vegetation due to climate change would be complicated, however, by the large densities of grazing and browsing ungulates, and by wildfire-suppression activities. Elk Island is relatively well-studied and heavily managed - animals are routinely culled and net primary production of browse and forage are measured to prevent overgrazing. The Park staff at Elk Island is already oriented towards ecological monitoring and soliciting cooperation from outside researchers.

The value of Elk Island as a reference-monitoring site may be enhanced as a result of the following activities: (1) The proposal for the U.S. Grassland Unit, which includes portions of North and South Dakota, has suggested the inclusion of Elk Island National Park as part of an international monitoring network. The U.S. Park Service has decided to fund the Grassland Unit proposal, and may be able to provide "hardware" for monitoring at Elk Island. (2) A multi-agency proposal has been submitted to the NSERC-NRC-SSHRC Environmental Tri-Council to form and study the Beaver Hills Biosphere Reserve. This reserve would be comprised of federal, provincial, and native lands that are adjacent to Elk Island. Within this program, monitoring and research activities conducted within Elk Island National Park would serve a reference function, while activities in the peripheral area would be integrated research and monitoring designed to investigate questions associated with important operational stressors, especially agriculture.

Yoho National Park, located on the border of Alberta and British Columbia, consists mostly of montane forest, a habitat which is limited in distribution in Canada and within the parks system. The park has winter range for deer, elk, and caribou (the latter being endangered in the region), and is a refuge and migration corridor for many large mammals. Supporting several large-carnivore species, the park has been proposed as a carnivore preserve under the World Wildlife Fund's Carnivore Conservation Strategy.

Yoho National Park is a particularly interesting candidate for an intensive-monitoring site because it is a large protected area, but one that is subject to disturbance, for example: (1) the trans-Canada highway bi-sects the park; and (2) very long freight trains (about 2 km in length) run their engines continuously while using the park for overnight-stopovers. In addition, forestry is actively practiced in the peripheral area of Yoho National Park.

Yoho National Park is currently being used as a case study for the development of long-range management plans for Canadian Parks Service. A circular planning process has been adapted

from the "Limits of Acceptable Change" (LAC) model, which was developed by the U.S. Forest Service to guide their decision making. To make the model more applicable to the Canadian Parks system, the LAC model was modified to incorporate a strong biophysical basis.

The first project under the LAC is to develop a long-range plan with respect to user groups in the Yoho Valley within the national park. Relevant indicators that are being evaluated for monitoring include water quality, user satisfaction, and the particular ecotourism opportunities provided to people. One of the ecological questions under study is: Why there are no grizzly bears in the valley -- have they been excluded by longer-term use of the valley by humans?

A Case Study for the Atlantic Maritime Ecozone: Kejimikujik National Park

In the Atlantic Workshop, Kejimikujik National Park (KNP) in southwestern Nova Scotia was considered as a relatively detailed case study for an intensive-monitoring site within the Maritime Atlantic Ecozone. Most attention focused on reference monitoring at KNP. However, forestry is being actively practiced in a large, crown-owned, wildlife-management area adjacent to KNP. It would be relatively straightforward to integrate reference-monitoring at KNP with experimental research and monitoring associated with forestry as a stressor in the peripheral area.

KNP encompasses 381 km² of terrain. The terrestrial landscape is about 94% forested as a complex post-fire and post-logging mosaic of mature stand types. There are 46 lakes and more than 30 streams and rivers in KNP, the largest of which is Kejimikujik Lake. Almost all surface waters are oligotrophic, shallow, and slightly-to-moderately acidic, and there is a high frequency of brown surface water due to organic drainage from *Sphagnum*-dominated wetlands. Within KNP there are 15 species of fish, 13 species of herptiles, 165 species of bird, and 44 species of mammal (Gimbarzevsky 1975; Kerekes *et al.* 1989; Kerekes and Freedman 1989; Drysdale 1990).

1) **Stressors.** The most important stressors affecting the region in which KNP is located were identified as:

a) **Atmospheric Deposition of Acidifying Substances.** Southwestern Nova Scotia receives an atmospheric deposition of acidifying substances that is moderate in intensity. The precipitation is acidic, with an annual average pH of 4.5-4.6, while the wet sulfate deposition is about 5.1 kgS/ha.yr, and dry deposition of sulfate plus sulfur dioxide is an estimated 2.1 kgS/ha.yr (Kerekes *et al.* 1989; Kerekes and Freedman 1989). The wet and dry depositions of other acidifying substances such as nitrate and ammonium are relatively small compared with more continental locations in eastern North America that are closer to large emissions sources (Kerekes *et al.* 1989; Kerekes and Freedman 1989).

b) **Climate Change.** As with the rest of the globe, southwestern Nova Scotia faces an uncertain intensity of climate change. It has been hypothesized that this is caused by anthropogenic emissions of radiatively-active gases such as carbon dioxide, methane, nitrous oxide, and others. The most likely scenarios of climate change involve a mean annual warming of perhaps several degrees centigrade, accompanied by a rise in mean sea level and changes in the amount and seasonality of precipitation (Freedman 1989).

c) **Ground-level Oxidants.** Compared with other monitoring stations in Canada, KNP experiences relatively large mean annual concentrations of ground-level oxidants, most notably ozone (EPS 1989a,b). This phenomenon is likely due to the long-range transport of ozone and/or its photochemical precursors, because the regional emissions of NO_x and hydrocarbons are relatively small, and climatic conditions that favour endogenous photochemical production of ozone and other oxidants (Freedman 1989) are uncommon in the region.

d) **Atmospheric Deposition of Trace Toxics.** Trace toxics include heavy metals, organochlorines such as PCBs, DDT, dieldrin, and various other pesticides. These chemicals are mostly emitted or entrained into the atmosphere in places outside the study area, and they are deposited only after being transported over a long distance. Trace toxics deposited at KNP could result from regional emissions in southwestern Nova Scotia or elsewhere in the Atlantic Maritime Ecozone, or they could be transported much longer distances from source areas in central Canada or the eastern United States.

e) **Stratospheric Ozone and Enhanced Flux of Ultraviolet-b.** A significant global depletion of stratospheric ozone may be occurring as a result of the anthropogenic emission of chlorofluorocarbons and certain other chemicals. Ozone "holes" are seasonal stratospheric phenomena that are most pronounced in polar latitudes during springtime. However, when the ozone-depleted atmospheric masses disperse they may cause a more widespread decrease in the stratospheric concentration of ozone (Freedman 1989). This effect could result in a seasonal, globally enhanced ground-level exposure to ultraviolet-B radiation, a component of the solar electromagnetic radiation spectrum that is highly energetic, and could cause detrimental biological effects such as increased rates of somatic mutation, increased incidence of skin cancers and cataracts, and photodecomposition of photosynthetic pigments and other biochemicals (Freedman 1989).

f) **Natural Stressors.** "Natural" stressors that are chronically or episodically important at KNP include wildfire, windstorms, epidemics of defoliating insects or diseases, and large populations of certain species of wildlife such as beaver and white-tailed deer. These all have the capability of causing important changes in the character of the environment and ecosystems of KNP.

g) **The Reference Function of Intensive-Monitoring Sites.** Because KNP is relatively remote and protected, it is mostly subject to the effects of stressors that are of regional, i.e. occurring generally in the Atlantic Maritime Ecozone. Because KNP is an ecological

reserve, local stressors such as those associated with forestry, agriculture, industrialization, and urbanization are not important, unless there is a long-distance transport mechanism (e.g., drift of pesticide sprayed outside of the park) or some other connection (e.g., insularization by forestry). Therefore, exposure and response indicators measured at KNP are useful in providing reference data for comparison with information collected in: (1) research or monitoring sites in the peripheral area, which might be experimentally or operationally perturbed in order to study the ecological effects of particular stressors, and (2) extensive-monitoring sites, which may be affected by more localized stressors.

2) Exposure Indicators. The intensities of stressors are measured using exposure indicators. Relevant exposure indicators that are presently being monitored at KNP are briefly described below, as are deficiencies in exposure monitoring that were identified during the workshop.

a) Atmospheric Deposition of Acidifying Substances. KNP is a sampling site in the Canadian Air and Precipitation Monitoring network (CAPMoN). Routinely collected information includes duplicate sampling of *wet-only precipitation events*, which are analyzed for major inorganic constituents (pH, sulfate, nitrate, chloride, calcium, magnesium, sodium, potassium, ammonium, acidity, and alkalinity (Vet *et al.* 1989)). These data can be used to calculate exposure indicators relevant to the wet deposition of acidifying substances, such as: (i) the concentrations of major inorganic constituents in precipitation events, for use in trajectory analyses to determine the origin of particularly acidic storm-bearing air masses, (ii) the annual or seasonal, volume-weighted, average concentrations of inorganic constituents in precipitation, and (iii) the seasonal and annual influxes of major inorganic constituents in wet deposition.

Other important exposure indicators of the atmospheric deposition of acidifying substances are relevant to *dry deposition*. These can be calculated from information on: (i) the atmospheric concentrations of particulate sulfate, nitrate, chloride, and ammonium, and (ii) the atmospheric concentrations of gaseous sulfur dioxide and oxides of nitrogen, coupled with (iii) knowledge of the deposition velocities of these substances to dominant ecosystem surfaces, such as lakes and forest. Although there have been periodic measurements of the above indicators of dry deposition at KNP (Wiebe *et al.* 1985; Kerekes *et al.* 1989), they are not routinely measured at present. This is a deficiency in the existing monitoring program at KNP for exposure indicators of the atmospheric deposition of acidifying substances.

b) Climate Change. KNP is a location for a Climate Station as part of the national network maintained by the Atmospheric Environment Service. The most useful, ground-level, climatic-exposure indicators are being measured at KNP, including shielded air temperature, precipitation volume, wind speed and direction, insolation, snow depth, and others.

c) **Ground-level Oxidants.** KNP is a sampling site in the National Air Pollution Surveillance Program (NAPS; EPS 1989a,b). The monitoring station at KNP continuously records the concentration of ground-level ozone, which is the most appropriate exposure indicator of ground-level oxidants.

d) **Atmospheric Deposition of Trace Toxics.** There have been occasional measurements of the atmospheric concentrations and/or depositions of certain trace toxics at KNP, but at present there is no monitoring program for this purpose.

e) **Stratospheric Ozone and Enhanced Flux of Ultraviolet-b.** There is no upper-atmospheric monitoring done at KNP, but regional data on stratospheric ozone are available from studies done at Sable Island, and information can also be extrapolated from computer modelling of the temporal dynamics of stratospheric ozone. Exposure indicators of the ground-level flux of UV-b can be inferred from changes in the concentration of stratospheric ozone, or such changes could be measured by wavelength-specific monitoring of this range of ultraviolet radiation. At present, such information is not available at KNP, and it is scarcely available anywhere in Canada.

f) **Natural Stressors.** As considered here, the most important "natural" stressors at KNP are wildfire, windstorms, epidemic populations of defoliating insects, diseases of wild life, and large populations of certain species of wildlife such as beaver and white-tailed deer. All of these can potentially cause important changes in the ecosystems of KNP. Appropriate exposure indicators of these natural stressors could be obtained by an intensification of already-existing monitoring programs, and could include the following:

(i) **wildfire** at KNP would be monitored by seasonal and annual data on the numbers of naturally ignited and human-caused fires, the area burned by each incident, and the plant communities and habitat types that are affected.

(ii) **windstorms** at KNP would be monitored by seasonal and annual data on the numbers of gale-force windstorms, the area of landscape over which significant damage is caused, and the plant communities and habitat types that are affected.

(iii) **epidemic populations of defoliating insects or wild life diseases** that cause important ecological changes (e.g. gypsy moth, spruce budworm, forest tent caterpillar, beech bark disease, etc.) would be monitored at KNP by collecting data on the annual abundance of the pests or the frequency of infection with the disease, the area of landscape over which significant damage is caused, and the plant communities and habitat types that are affected.

(iv) **certain species of wildlife such as beaver and white-tailed deer** are capable of causing important ecological changes. This is especially true when these occur in dense populations, as at KNP. Exposure indicators of these natural stressors at KNP could include annual estimates of their abundance and distribution, the area of

landscape over which significant damage is caused, and the plant communities and habitat types that are affected.

To summarize, exposure indicators are largely available at the present, except for those relating to atmospheric deposition of trace toxics and stratospheric ozone and enhanced flux of ultraviolet-b, for which indicators are deficient.

3) Response Indicators. The effects of exposure to stressors are monitored through various response indicators. During a workshop exercise on the design of an intensive-monitoring program, a list of desirable, potentially-useful response indicators was identified that could be monitored at KNP. This list is presented below, along with a brief description of sampling. The list of indicators is rather comprehensive in length and detail, and perhaps unrealistic in terms of the likely funding that will be available for a national Ecological-Monitoring Program in Canada. Therefore, an operational monitoring program at KNP would probably involve a shorter list of prioritized response indicators than is discussed here. Following this section, the availability of the indicators is summarized in tabular, matrix format.

Aquatic Systems. At KNP, it would be appropriate to choose 3-5 lakes for intensive-monitoring. Preferably, each of these would be an oligotrophic headwater lake with a relatively small watershed. Each would have an outflow capable of being gauged so that water and chemical fluxes could be determined, and it would be remote and not subjected to intensive recreational use. The 3-5 lakes chosen for intensive-monitoring would encompass the range of water chemistry at KNP, especially in terms of acidity and dissolved organic carbon. Various response indicators would be measured at each lake, as is described below:

a) Aquatic Systems, Physical/Chemical Indicators.

i) **Major Ion Concentration.** Concentrations of major ions can change in response to variations of the chemical quality of atmospheric deposition, and to changes in the ecological character of the landscape. Therefore, this indicator is useful for the detection of changes that might be caused by significant exposure to various stressors (see table). Sampling for major ions would be done monthly at the lake's outflow during the growing season, and less frequently during winter depending on conditions of access. Analysis would be for major ions (calcium, magnesium, hydrogen ion, potassium, sodium, aluminum, iron, manganese, zinc, sulfate, chloride, alkalinity, nitrate), colour, and total and dissolved organic matter.

ii) **Watershed Hydrology.** Water flow and other elements of the hydrologic budget can change in response to variations of precipitation amount, and to changes in the ecological character of the landscape, especially changes in vegetation that affect transpiration. Therefore, this indicator is useful for the detection of changes that might be caused by significant exposure to various stressors. Hopefully, the

outflow(s) of the waterbody would be gauged. This information, coupled with data on precipitation inputs of water, and calculation of seasonal evapotranspiration based on a bioclimatic model, would allow the monitoring or calculation of all important elements of the hydrologic budget of the lake's watershed.

iii) **Major Ion Flux.** This indicator integrates the effects of changes in watershed hydrology and major ion concentration, and it is useful for monitoring changes caused by significant exposure to various stressors. Assuming that the outflows of the study lakes were gauged, the flux of major ions would be calculated by multiplying concentration times flow.

iv) **Plant Nutrients.** Trophic status is largely influenced by the availability of phosphate to primary producers, which can be affected by changes in the exogenous inputs of phosphorus compounds, and by changes in endogenous phosphorus cycling. These can be affected by exposure to various stressors. As an indication of trophic status of the waterbody, concentrations of orthophosphate, total dissolved phosphorus, and total phosphorus would be determined on samples collected according to the schedule in (i) above.

v) **Trace Elements.** Trace element concentrations in water can be affected by changes in the rate of exogenous input of long-range transported emissions, or more likely by various hydrologic or chemical (especially acidification) changes within the watershed that influence the mobilization of relatively insoluble mineral compounds of trace metals, so that they can occur in larger concentrations in water. The concentrations of a suite of trace elements (including As, Cd, Co, Cr, Cu, F, Pb, Hg, Mo, Ni, Se, Sn, Ti, U, V, and Zn) would be determined in outflow samples collected 2-4 times per year.

vi) **Trace Toxics.** The concentrations of trace toxics in water are influenced solely by atmospheric deposition to the lake and its watershed, coupled with the effects of *in situ* chemical degradation or immobilization from the water column. This response indicator is only relevant to exposure to atmospheric deposition of trace toxics, and to the reference function of an intensive-monitoring site.

b) **Aquatic Systems, Biological Indicators.** The standing crop, abundance, taxa, and productivity and other functional attributes of aquatic organisms and communities can be variously affected by changes in water quality in terms of nutrient and toxic substances, by changes in the nature of herbivory or predation, and by other effects. These can be variously affected by exposure to various stressors (see table). For example, the abundance and species composition of the phytoplankton can be variously affected by changes in trophic status of the waterbody, by changes in toxic chemicals associated with acidification, by extreme weather, climate change, and by changes in the nature and intensity of predation by zooplankton. The most useful biological indicators of response that might be measured in the intensively studied lakes at KNP are:

i) **Microbial Community and Function.** Sampling of the abundance of taxa of bacteria and fungi and selected processes carried out by microbes (for example litter decomposition, oxidation of organic-P to phosphate, or nitrification) could be monitored at a permanent deepwater station, probably at several times during the growing season.

ii) **Phytoplankton Community and Function.** Phytoplankton standing crop, the abundance of taxa, productivity and other functional attributes could be monitored at a permanent deepwater station, perhaps monthly during the ice-free season.

iii) **Periphyton Community and Function.** Standing crop, abundance, and productivity of the periphyton could be sampled at a set of permanent littoral stations, possibly monthly during the ice-free season.

iv) **Macrophyte Community.** Macrophyte cover, standing crop, and species composition could be sampled separately in the littoral zone and deepwater, using permanent sampling stations, and a single annual measurement at the peak of the growing season.

v) **Zooplankton Community.** The biomass, abundance, size spectrum, and species composition of the zooplankton could be monitored at a permanent deepwater station, with a single sampling, probably at peak-season in August.

vi) **Benthic Invertebrate Community.** The biomass, abundance, and species composition of benthic invertebrates could be monitored at a permanent deepwater station, with a single sampling, probably at peak-season in August.

vii) **Fish Community.** The size spectrum, abundance, and species composition of fish could be monitored at permanent sampling stations, with a single sampling at peak-season in August, and using non-lethal trap-nets.

viii) **Aquatic Bird Community.** The abundance, fledging success, and species composition of aquatic birds could be monitored annually in August. For this indicator, a larger set of sample lakes within KNP would be required.

ix) **Amphibian Community.** The abundance of adults and egg masses of various amphibian species could be monitored annually, at various times depending on the breeding schedule of species. For this indicator, a larger set of permanently-sampled wetland types within KNP would be required.

c) **Aquatic Systems, Bioconcentration.**

i) **Toxics in Macrophytes.** Two to four species of abundant and widely dispersed macrophyte species would be sampled on each intensive-study lake for analysis of

selected trace metals and organic toxics. Sampling would be done at permanent stations, in August.

ii) **Nutrients in Macrophytes.** Two to four species of abundant and widely dispersed macrophyte species would be sampled on each intensive-study lake for analysis of macronutrients (N, P, K, Ca, Mg, S). Sampling would be done at permanent stations, in August.

iii) **Toxics in Benthos.** Two to four species of abundant and widely available benthic invertebrates would be sampled on each intensive study lake for analysis of selected trace metals and organic toxics. Sampling would be done at permanent stations, in August.

iv) **Toxics in Fish.** One or two species of abundant and widely available fish species would be sampled on each intensive study lake for analysis of selected trace metals and organic toxics. Sampling would be done in August.

Terrestrial Systems. It would be appropriate to choose 5-10 sites in representative mature forest types for intensive-monitoring at KNP. Preferably each would be in the watershed of one of the intensively-monitored lakes, and the stands would encompass the range of typical variation among forest types at KNP. Various response indicators would be measured at each site:

a) Terrestrial Systems, Physical/Chemical Indicators.

i) **Forest Soil, Chemical Quality.** On each sampling date, a set of randomly selected soil pits would be sampled by definable horizon for the determination of acidity, concentration and amount-per-unit-area of organic matter, total N, P, K, Ca, Mg, and S, and available or exchangeable ions of these nutrients. Sampling could be done every 2-5 years, late in the growing season, in permanent locations within the terrestrial intensive-monitoring sites. Additional, more-frequent sampling of the chemical composition of soil water could be performed using permanently installed sampling wells or lysimeters.

b) **Terrestrial Systems, Biological Indicators.** As with aquatic systems, the standing crop, abundance, species composition, and functional attributes of terrestrial organisms and communities can be variously affected by exposure to various stressors (see table). For example, the biomass and productivity of tree species can be variously affected by acidic deposition, gaseous air pollutants, nutrient availability, extreme weather, climate change, and herbivory. The most useful biological indicators of response that might be measured in the intensively-studied terrestrial sites at KNP are:

i) **Microbial Function.** Selected processes carried out by microbes (for example litter decomposition, litter accumulation, nitrification, or dinitrogen fixation) could be monitored at permanent sampling stations at each intensive study site, probably at several times during the growing season.

ii) **Forest Vegetation, Community.** At each of the mature forested sites selected for intensive-monitoring at KNP, permanent plots would be established for measurement of vegetation. Plot size would be appropriate for separate sampling of variously sized plants, perhaps: 5-10 plots of 20m x 20 m for trees, 10-20 plots of 5m x 5m for shrubs, 20-40 plots of 1m x 1m for ground vegetation, and 10-20 trees for measurement of epiphyte communities. Estimates would be made of foliar cover by species, and biomass could be calculated using equations that relate biomass to some non-destructive measurement (e.g., log biomass versus log tree diameter).

iii) **Forest Vegetation, Function.** Selected functional attributes could be measured in permanent plots at each of the forested sites selected for intensive-monitoring. Useful examples include net production, litterfall, and phenology of selected, widespread species.

iv) **Invertebrates, Forest Floor, Community.** The abundance and species composition of invertebrates in the forest floor could be monitored at permanent sampling stations at each intensive study site, probably on several dates during the growing season.

v) **Invertebrates, Canopy, Community.** The abundance and species composition of invertebrates in the forest canopy could be monitored at permanent sampling stations at each intensive study site, probably on several dates during the growing season.

vi) **Amphibians, Community.** The abundance and species composition of amphibians, notably salamanders, in the forest floor could be monitored at permanent sampling stations at each intensive study site, probably on several dates during the growing season.

vii) **Birds, Community.** The abundance and species composition of breeding birds could be censused by spot-mapping in the springtime at a total of 2-4 permanent, 10-40 ha sampling plots at selected intensive study sites.

viii) **Small Mammals, Community.** The abundance and species composition of small mammals could be censused by live-trapping several times during the growing season at a total of 2-4 permanent, 10-40 ha sampling plots at selected intensive study sites (i.e., the same plots used to study birds).

ix) **Large Mammals, Community.** The abundance of large mammals could be monitored by whole-park or other substantial-area censuses at appropriate times of

year. For example, deer and coyote could be counted on permanent aerial transects in winter, or beaver could be indexed by lodge counts.

c) Terrestrial Systems, Bioconcentration.

i) **Toxics in Plants.** Foliage of 2-4 species of abundant and widely dispersed plant species and 2-4 epiphytic lichens would be sampled at each or selected intensive study sites for analysis of selected trace metals and organic toxics. Sampling would be done at permanent stations, in August.

ii) **Nutrients in Plant Foliage.** Foliage of 2-4 species of abundant and widely dispersed plant species would be sampled at each intensive study site for analysis of macronutrients (N, P, K, Ca, Mg, S), at permanent stations in August.

iii) **Toxics in Amphibians.** A common terrestrial amphibian, such as the red-backed salamander, could be sampled at each of the 2-4 bird census plots for analysis of selected trace metals and organic toxics, at permanent stations in August.

iv) **Toxics in Small Mammals.** A common small mammal, such as the red-backed vole or short-tailed shrew, could be sampled at each of the 2-4 bird census plots for analysis of selected trace metals and organic toxics, at permanent stations in August.

For integrated monitoring at an intensive-monitoring site such as KNP, response indicators are mostly designed to detect change, in the broader sense. Specific responses caused by exposure to particular stressors are not usually investigated during monitoring [although, as is discussed in our framework document (Freedman *et al.* 1993), those sorts of cause-and-effect questions could be asked during secondary, possibly longer-term research designed to elucidate the causes of changes that may have been monitored in response indicators]. Therefore, most response indicators are suitable for monitoring changes that might result from exposure to more than one stressor. This overlap in the utility of many response indicators is illustrated in matrix form in the table that follows (note that all exposure indicators are relevant to the reference function of monitoring at an intensive-monitoring site). The matrix also notes whether, in the opinion of workshop participants, information suitable for monitoring purposes is presently available for the proposed response indicators. Perusal of the matrix reveals that, in almost all cases, the response indicators are currently deficient.

Matrix of Stressors and Indicators. Stressor vs. exposure or response indicator matrix for the Kejimikujik National Park case study. This matrix lists stressors that are regionally important in the Atlantic Maritime Ecozone, versus response indicators that would be suitable to measure environmental change at any Intensive-Monitoring Site. See text for a brief description of the proposed indicators. **A** denotes the information is currently available; **a** denotes some information is currently available, but there are important deficiencies; **D** indicates the information is not currently available; - indicates the indicator is not very relevant to the particular stressor.

Indicators	Stressors						
	Acidic Depos.	Climate Change	Ground Oxidant	Trace Toxics	Strato. Ozone	Natural Stressors	Reference Function
EXPOSURE (see text)	A	A	A	D	D	A	A
RESPONSE							
Aquatic Systems							
<u>Physical/chemical</u>							
major ion concentration	a	a	-	-	-	a	a
watershed hydrology	a	a	-	-	-	a	a
major ion flux	a	a	-	-	-	a	a
plant nutrients	a	a	-	-	-	a	a
trace elements	D	D	-	D	-	D	D
trace toxics	-	-	-	D	-	-	D
<u>Biological</u>							
microbial community	D	D	-	-	-	D	D
microbial function	D	D	-	-	-	D	D
phytoplankton commun.	D	D	-	-	-	D	D
phytoplankton function	D	D	-	-	D	D	D
periphyton community	D	D	-	-	-	D	D
periphyton function	D	D	-	-	-	D	D
macrophyte community	D	D	-	-	D	D	D
zooplankton community	D	D	-	-	-	D	D
benthic invert. comm.	D	D	-	-	-	D	D
fish community	D	D	-	-	-	D	D
aquatic bird community	D	D	-	-	-	D	D
amphibian community	D	D	-	-	-	D	D

Stressor vs. indicator matrix for the Kejimikujik National Park case study (continued):

Indicators	Stressors						Reference Function
	Acidic Depos.	Climate Change	Ground Oxidant	Trace Toxics	Strato. Ozone	Natural Stressors	

RESPONSE INDICATORS							
Aquatic Systems (continued)							
<u>Bioconcentration</u>							
toxics in macrophytes	D	-	-	D	-	-	D
nutrients in macrophytes	D	D	D	D	-	D	D
toxics in benthos	D	-	-	D	-	-	D
toxics in fish	D	-	-	D	-	-	D
Terrestrial Systems							
<u>Physical/chemical</u>							
forest soil, chemistry	D	-	-	D	-	-	D
<u>Biological</u>							
forest vegetation							
community	D	D	D	-	D	D	D
function	D	D	D	-	D	D	D
invertebrates							
forest floor							
community	D	D	-	-	-	D	D
function	D	D	-	-	-	D	D
forest canopy							
community	D	D	-	-	-	D	D
function	D	D	-	-	-	D	D
amphibians, community	D	D	-	-	-	D	D
birds, community	D	D	-	-	-	D	D
small mammals, comm.	D	D	-	-	-	D	D
large mammals, comm.	D	D	-	-	-	D	D
<u>Bioconcentration</u>							
toxics in plants	D	-	-	D	-	-	D
nutrients in foliage	D	D	D	-	D	D	D
toxics in amphibians	D	-	-	D	-	-	D
toxics in small mammals	D	-	-	D	-	-	D

Potential Intensive-Monitoring Sites in the Northern Region

Participants at the Northern Region workshop identified sites in the Northwest Territories and Yukon with a history of relatively intensive, longer-term ecological research and monitoring. These sites are (in alphabetical order): Alexandra Fiord and Sverdrup Pass on Ellesmere Island, the Coppermine - Bathurst Inlet, Eureka and the Fosheim Peninsula on Ellesmere Island, Manor's Creek vicinity at the confluence of MacKenzie and Liard Rivers, Fort Providence vicinity at western Great Slave Lake, Great Plain of the Koudjuik on Baffin Island, Kent Peninsula near Cambridge Bay, Kluane Research Station in the Yukon, Inuvik vicinity in the Mackenzie River delta, Polar Bear Pass on Bathurst Island, Thelon Game Reserve, Thompson River area on Banks Island, Truelove Lowland on northern Devon Island, and Wood Buffalo National Park.

Truelove Lowland as an Intensive-Monitoring Site in the Northern Region

Workshop group 1 briefly developed a conceptual design for an intensive-monitoring site. As a model, the existing longer-term ecological research site at Truelove Lowland on the north shore of Devon Island was considered.

Truelove Lowland is a coastal lowland that because of its relatively warm and protected location sustains an ecological "oasis" in a landscape that is dominated by high-arctic polar desert and semi-desert. There is a well-developed matrix of terrestrial vegetation types separated according to drainage and exposure, and there are some thermokarst ponds and lakes. The site also has an outlet lobe of an upland glacier. The community of Grise Fiord is on southern Ellesmere Island, and where possible that community should be involved in the monitoring program and its logistics. The following summarizes the elements of the design of an intensive-monitoring site located at Truelove Lowland:

a) Atmospheric Chemistry

- a single station could be established for monitoring carbon dioxide and other radiatively-active gases, located remote from any local sources of emission associated with the research station.

b) Ice Cap and Outlet Lobes

- outlet lobes - permanent transects should be established for monitoring the frontal dynamics of at least one outlet lobe of the upland glacier.
- mass-balance - an estimation protocol might be developed for periodic monitoring of mass of the upland glacier, which might be expected to change with climate warming.

c) On the Lowland Oasis

- climate - monitor standard climate indicators of air and surface-soil temperature, precipitation volume and type, insolation quantity and quality, humidity, etc. The spatial design might include a coastal station, and several inland stations stratified by major plant-community type. UV-b should be monitored at one station.
- soil - monitor standard indicators of soil structure and chemistry, such as percent organic concentration, nutrient concentration in total and plant-available chemical forms, and concentrations of selected trace toxics. The spatial design should involve a network of permanent plots in prominent plant-community types, in conjunction with the vegetation sampling.
- vegetation - species composition, biomass, and productivity could be monitored in a network of permanent plots located in prominent community types. Several wide-ranging species of lichen and higher plant could be selected for bio-monitoring of concentration of selected trace toxics.
- avifauna - species composition and abundance, using an annual whole-lowland census.
- aquatics - species composition and peak-season standing crop of phytoplankton and zooplankton could be monitored, along with standard indicators of water chemistry.

d) On the Upland (Desert) Plateau

- climate - the same climate indicators as on the lowland oasis, but at 1-2 stations.
- soil - the same indicators as on the lowland, in the same plant-community types in which upland vegetation is monitored.
- vegetation - species composition and productivity, at 2-3 semi-desert or desert sites.

e) In the Nearby Marine Environment

- trace toxins could be monitored in ringed seal and a species of fish, perhaps with the assistance of persons from the community at Grise Fiord.

Indicators of Climate Change for Reference-Monitoring in the Prairie Region

During the Prairie Region workshop, the following list of indicators was developed for reference-monitoring of the effects of climate change at a generic, intensive-monitoring site. Note that the atmospheric indicators would be rather specific indicators of climate change, while the biological indicators could be affected by a wide range of stressors that would include climate change.

a) Atmospheric Indicators

- temperature - annual and growing season (degree-days), extremes (daily, annual).
- precipitation - total amount, as rain or snow, snow depth, extreme events.
- insolation - total radiation, net radiation by major ecosystem surface, photosynthetically active radiation, UV-b.
- wind - speed, direction, extreme events.
- potential evapotranspiration - modelled.
- concentration of greenhouse gases.

b) Aquatic Indicators

- surface water - lake levels, lake water balance, streamflow, ice cover, thermal budget, turnover time, depth of thermocline.
- water chemistry - concentration and budgets of nutrients.
- biological structural indicators - community composition, diversity, and biomass, separately for major trophic levels (phytoplankton, zooplankton, benthos, fish, etc.).
- biological functional indicators - productivity, nutrient cycling, etc., separately for major trophic levels.
- paleoclimatological and paleobiological indicators may provide useful retrospective data, e.g. palynology, diatom reconstructions, etc.

c) Terrestrial Indicators

- groundwater - height of water table, major chemistry.
- soil - using standard indicators (see agriculture).

- biological structural indicators - as for Aquatics (above); major biotic compartments (e.g., vegetation, arboreal and soil arthropods, small mammals, avifauna).
- biological functional indicators - as for Aquatics (above), separately for major biotic compartments.

Intensive-Monitoring of Ecological Changes Associated with Agriculture

In the Prairie Region workshop, an intensive-monitoring design was outlined to experimentally investigate the longer-term environmental effects of selected agricultural scenarios in the Prairie Region. The model was developed from a research program of Martin Entz and co-workers at the University of Manitoba, who are engaged in longer-term (15-year) research of ecological changes associated with intensive agriculture in chernozem soils in southern Manitoba. Entz is studying two types of rotation: (1) wheat-barley-field pea, and (2) 1-10 years of pasture, followed by conversion to wheat-barley-field pea. Each scenario has a nitrogen-fertilizer addition/no addition (+) treatment, and a $\pm$ pesticide treatment. Native tall-grass prairie is the reference ecosystem.

The indicators that Entz is using to monitor changes in soil quality include the following:

- soil erodibility index
- microbial population and biomass
- total soil nitrogen and organic carbon
- mass balances for N, P, K, S, in 240 cm of surface soil
- soil water budget
- soil salinity

The following indicators are being used to monitor changes in ecosystem productivity:

- crop yield
- nutrient uptake by vegetation
- crop diseases
- abundance of "weeds"
- abundance of arthropod pests

Indicators relevant to the economic sustainability of the scenarios are also being monitored.

Discussion during the workshop generally supported this design for a model of intensive-monitoring of response to agricultural stressors. However, because Entz' research is relatively focused on indicators of direct economic interest, some deficiencies were identified in the research design. These include indicators of non-economic response (such as non-economic mammals, birds, and plants), atmospheric conditions, and climate change.

Intensive, Integrated Monitoring of a Prairie Grassland Ecosystem

The Matador Project in southwestern Saskatchewan provides a case study of integrated, intensive-monitoring of a prairie grassland ecosystem. The University of Saskatchewan developed the Matador Project in 1967 as one of the Canadian sites in the International Biological Programme (IBP). The site for the Matador Project is one of the few remaining, extensive ($>38 \text{ km}^2$), uncultivated areas of arable clay soil in the Canadian Prairies. The integrated research program at Matador has involved nearly 100 persons, under the direction of about two dozen scientists. Ongoing activities include: (1) regular determinations of biomass of each of the major plant and animal species on site; (2) continuous monitoring of the atmospheric and soil environment; (3) field and laboratory experiments to determine interactions within the ecosystem and responses to environmental perturbations; and (4) development of a computer model to integrate all of the information obtained into a usable form.

Integrated Monitoring for the Effects of Pesticides in Prairie Region

A case study of a developing, integrated monitoring program in the Prairie provinces involves regional monitoring of pesticide effects by the Canadian Wildlife Service. This program is briefly described below.

Extensive-monitoring is being conducted of two passerine species, bluebird and tree swallow, that are potential indicators of pesticide effects on insectivorous birds. The indicator species are representative of prairie passerines, cost-effective to monitor on a large scale, and important to the general public. This program involves the co-ordination of volunteer naturalists to collect data on the reproductive success of birds that utilize nest-boxes that have been established throughout the region. These data are analyzed in relation to information on pesticide application in the vicinity of the nest boxes, which is obtained from farmers and municipalities.

This CWS program is integrating extensive-monitoring, described above, with intensive avian studies. Intensive sites are being developed by establishing nest-boxes in ecological reserves. These sites will serve two purposes: (1) experimental study of insecticides for which preliminary data, from the extensive-monitoring program, indicate adverse effects, and (2) longer-term monitoring of reference changes in protected sites. Furthermore, a multi-disciplinary approach is being used in these intensive studies, so that changes in invertebrate abundance due to pesticide application will also be documented.

In addition, habitat will be surveyed for evidence of vegetation changes that can be attributed to herbicide use, such as loss of particular plant species important to wildlife as food or cover.

The Experimental Lakes Area as an Intensive-Monitoring Site

The Experimental Lakes Area (ELA) of northwestern Ontario is world-famous for its programs of longer-term ecological research, including both reference monitoring and whole-ecosystem experimental manipulations designed to simulate exposure to important anthropogenic stressors, followed by longer-term monitoring to investigate ecological response. Not only is the response to induced stress monitored, but monitoring continues during the controlled recovery phase, to investigate response to abatement or mitigation. Furthermore, ELA has a growing priority to investigate, implement, and recommend remedial measures. For example, enhancement of sedimentation through nutrient-induced manipulation of phytoplankton may provide a method for sequestering added cadmium into sediment, thereby removing it from the system.

Research in the Experimental Lakes Area is largely an effort of the Freshwater Institute of the Department of Fisheries and Oceans. However, there has been a diverse collaboration with other agencies of the federal and provincial governments, universities (numerous graduate students from many institutions have performed their thesis research at ELA), and the international community.

The ELA has a well-established program for monitoring hydrological, meteorological, and limnological aspects of lake ecosystems. Moreover, several of the reference lakes at ELA have had longer-term monitoring of abundance and species composition of water chemistry, phytoplankton, zooplankton, benthic invertebrates, and fish communities, as well as functional indicators related to productivity and nutrient cycling.

A great strength of the ELA program has been its history of whole-ecosystem manipulations designed to simulate the longer-term ecological responses to exposure to important anthropogenic stressors. Examples of some of the whole-ecosystem experiments carried out or planned include the following:

- (1) A series of whole-lake experiments was designed to investigate the role of specific nutrients in causing eutrophication of oligotrophic lakes. This famous ELA research was central in the identification of phosphorus as the primary limiting nutrient causing eutrophication of freshwaters, and the work has had an important influence on the ways in which governments have pursued strategies for the avoidance or mitigation of this environmental problem.
- (2) A series of whole-lake and whole-wetland acidification experiments was designed to investigate ecological response, in terms of both biogeochemical and biological indicators, to this widespread type of environmental degradation.
- (3) Other whole-ecosystem experiments have been conducted, including one in which cadmium was added to investigate environmental toxicology and biogeochemical cycling of this pollutant, and another in which a radioelement was added to examine the potential ecological implications of deliberate disposal or accidental release of radioactive metals.

(4) Two other whole-ecosystem manipulations are in advanced planning, including an experimental flooding of a small watershed to examine the ecological effects of reservoir development for hydroelectric purposes, and a whole-lake PCB addition to investigate the environmental toxicology and biogeochemical cycling of this controversial persistent chemical. (It now appears likely that, in accordance with its zero-discharge policy, the Government of Ontario will not allow the experimental PCB addition to proceed, even though the target concentrations in water were similar to those occurring in Lake Ontario.)

Results from unperturbed, reference sites have also demonstrated the importance of longer-term monitoring. For example, Schindler and colleagues have recently examined the effects of changes in climate on the limnology of a reference lake at ELA. This study, which is one of the few demonstrations of the effects of climatic warming on an ecosystem scale, used data collected as part of the standard reference-monitoring program at ELA.

Collectively and individually, the research at ELA represents one of the most important longer-term programs in Canada for the monitoring of reference ecological conditions, and the effects of stressors associated with human activities.

To date, ELA research has focused on aquatic ecosystems, which is not surprising, considering the mandate of the lead agency, the Department of Fisheries and Oceans. Detailed information is lacking with respect to the structure and function of the terrestrial components of the study watersheds. Therefore, current ELA programs are deficient with respect to providing a model for an intensive-monitoring site, in the integrated sense considered in the conceptual framework discussed in Freedman *et al.* (1993). This deficiency could be readily addressed, however, by institutionalizing terrestrial-related monitoring into the ELA program, thereby ensuring an appropriately-integrated monitoring and research design.

It should be noted that the ELA research site has been under-funded in recent years. The programs at ELA are at risk of significant down-sizing, and even abandonment. From the perspective of ecosystem science in Canada and beyond, this would be a tragic event. Directly pertinent to the theme of the present report and Freedman *et al.* (1993) is the question that, if there is insufficient funding for longer-term monitoring and research at this single, world-class, intensive site, then how could a national network of such sites be supported without a considerable infusion of funding?

Dorset Research Centre as a Candidate Intensive Site

The Dorset Research Centre has been conducting integrated ecological-monitoring and research in south-central Ontario, in co-operation with other agencies of the provincial and federal governments, several universities, and the private sector. These studies have tended to focus on atmospheric processes and limnology and stream ecology, with little attention to the terrestrial parts of the watershed. The diverse list of Dorset research and monitoring activities includes: (1) longer-term monitoring of many indicators of environmental quality, along with

(2) more question-oriented research focused on the ecological/environmental responses to exposure to particular stressors that are considered important from the perspective of Ontario Ministry of the Environment.

The existing program of integrated ecological research at Dorset Research Centre could readily be expanded into an intensive-monitoring site of the sort envisioned in the Dalhousie framework document. Clearly, Dorset should be identified as a candidate site for the emerging program being developed by the federal government.

Norman Yan's program for monitoring zooplankton is an example of how intensive and extensive-monitoring can be integrated. The program is briefly summarized below:

- (1) Zooplankton data were collected on three scales: 600 lakes across the province sampled once, 60 lakes sampled for at least one entire ice-free season, and 8 lakes with continuous data over 10-15 years.
- (2) All data are on-line in a relational database. The 600-lake data set is at Laurentian University.
- (3) Sample collection protocols were compared with those of CCIW and ELA (in prep.).
- (4) All samples are maintained in an archive with electronic cross-reference to the actual data generated by sample enumeration.
- (5) Samples are processed using a semi-automatic counting system that produces inputs to the database immediately.

REGIONAL STRESSORS

Introduction

Participants in each of the more formal workshops identified a list of stressors that, by consensus, were believed to be actually or potentially important in causing environmental change in their region. As such, monitoring these stressors, and also the exposure and response to these stressors, would be warranted.

Below, these stressors are listed (in no particular order) for each region in which a formal workshop was held (Atlantic, Pacific, Northern, and Prairie). In addition to these specific stressors, workshop participants suggested monitoring for other, unanticipated stressors, i.e. "surprises."

Atlantic Region

The following stressors were identified as having potentially important effects in the Atlantic Region (see also the case study of Kejimikujik NP for further discussion of regional stressors):

- 1) **Land use** can range from industrial use to natural habitat, with the former having a greater effect on the character of the land. Examples include sites of power generating stations, transmission lines, oil refineries, steel plants, pulp mills, dams, roads, and more extensive land use such as residential development, agriculture, forestry, or mining.
- 2) **Resource extraction** refers to activities associated with agriculture, forestry, mineral extraction, mining, hunting, fishing.
- 3) **Industrial emissions** refer to emissions from point-sources (e.g., power plants, pulp and paper mills, smelters, etc.) that have localized effects on the surroundings of the facility.
- 4) **Climate Change** may be influenced by changes in atmospheric concentrations of carbon dioxide, methane, nitrous oxides, and other greenhouse gases. Effects could include an increase in global temperature, which could alter patterns of precipitation, species distribution, and sea level, among other effects (Freedman 1989). Climate change could also occur through thinning of the stratospheric ozone layer, resulting in an increase in harmful ultra-violet radiation reaching the surface of the Earth (Freedman 1989).
- 5) **Long Range Transport of Air Pollutants (LRTAP)** refers to atmospheric pollutants originating from sources outside the ecozone, and transported to the Atlantic Maritime region. Examples of LRTAP include acidic deposition, sulfur dioxide, ozone, etc. Much of the ecozone has soil and bedrock types with little acid-neutralizing ability, rendering large areas sensitive to acidification (Environment Canada 1988; FPRMCC 1990). Ground-level oxidants have recently received attention in this area, and may play a role in the dieback of White Birch along the Fundy coast (Cox *et al.* 1989).
- 6) **Natural Disturbance** includes fire, windstorm, outbreaks of insect pests.

Pacific Region

At the Pacific Region workshop, six major stressors affecting B.C. were identified, and then categorized by air, water, and land effects:

- 1) **Land Use** - forest land base, urban development, agriculture, mining;
- 2) **Freshwater** - over-use, contamination, flow regimes (siltation etc.), irrigation use and allocation, drinking water supply, over-use and contamination of groundwater;
- 3) **Marine** - contamination of deep-sea and foreshore environments, over-fishing, harvesting, global climate effects on sea level and circulation;
- 4) **Air** - airsheds in urban areas, long-range transport of air pollutants, industrial emissions;
- 5) **Energy** - flooding, transportation of energy, global effects, domestic and industrial use;
- 6) **International** - air, water.

Importance of Various Stressors to the Five Ecozones in B.C. Workshop participants considered the importance of various stressors to the different ecozones. The matrix below indicates the importance (actual or potential) of particular stressors in the five ecozones in B.C. An X indicates that the stressor is believed to be of actual or potential importance from the perspective of extensive-monitoring in the ecozone, while 0 indicates that it is not.

	Coastal	Boreal Interior	Boreal Cordillera	Boreal Plains	Taiga
Forestry					
- harvesting	X	X	X	X	X
- silviculture	X	X	X	X	X
- manufacturing	X	X	X	X	X
Climate Change	X	X	X	X	X
Tropospheric Pollution					
- SO ₂ , NO _x	X	X	0	0	0
- O ₃	X	X	0	0	0
Stratospheric O ₃	X	X	X	X	X
Atmosph. Trace Toxics	X	X	X	X	X
Mining	X	X	X	0	0
Fishing	X	X	X	X	X
Hunting	X	X	X	X	X
Tourism	X	X	X	X	X
Agriculture	X	X	0	X	0
Waste Disposal	X	X	X	X	X
Urbanization	X	X	0	0	0
Hydroelectric	X	X	X	X	X
Other Land Use	X	X	X	X	X
Natural Stressors	X	X	X	X	X
Unidentified Stressors	X	X	X	X	X

Stressors Relevant to Coastal Zone Management in B.C.

Participants in the Pacific Region workshop identified the following activities as being stressors relating to coastal zone management in B.C:

- recreation
- oil tanker traffic
- other shipping
- oil exploration and development
- commercial fishery - aquaculture
 - salmon
 - other species
- effluents
- ocean dumping
- shoreline development
- freshwater export
- indirect forestry effects and log booms

Northern Region

Participants in the Northern Region workshop developed a list of stressors thought to have an important affect on the Northern Region (specifically the Northwest Territories) includes (in no particular order):

LRTAP - long-range transported air pollutants, including trace toxics, acidifying substances (acid rain), haze, and radionuclides.

LRTAqP - long-range transported aquatic pollutants, including oxygen-consuming pulp-mill effluents, and organohalines. Some of these are not relevant to both marine and freshwater (especially river) ecosystems.

Stratospheric ozone and enhanced flux of biologically damaging **ultraviolet-B radiation**.

Climate change, occurring naturally or forced by human activities, for example by enhancement of the greenhouse effect as a result of the emission of radiatively-active gases to the atmosphere.

Variability in climate, including precipitation.

Human population growth, a stressor that integrates many separate activities that affect environmental quality.

Hunting, fishing, and trapping as human activities that exploit wild animal populations.

Forestry, which in the NWT mostly involves harvesting.

Sewage disposal into surfacewater and the ocean. This stressor is only of local importance in causing environmental change.

Waste disposal, including solid wastes, toxic wastes, persistent litter, and the abandonment of scientific camps and other facilities.

Mineral industries, including activities associated with exploration, extraction, processing (milling, smelting, refining), and the abandonment of worked-out or commercially marginal sites.

Oil and gas industries, including activities associated with exploration, production, refining, and transportation.

Hydroelectric development.

Marine shipping, especially seasonal traffic, although becoming increasingly year-round.

Highways and other major roads, including permanent and winter roads.

Mosquito spraying, which has localized effects.

Tourism.

Wildfire, especially as a potential stressor to certain boreal wildlife; also fire suppression.

Flooding, especially events associated with ice dams on major rivers.

Epidemics of insects and diseases of ecological importance (e.g., spruce budworm).

Overgrazing by wildlife and semi-domestic animals (e.g., reindeer).

Isostasy (post-glacial uplift) and other geomorphic changes.

Permafrost.

Habitat changes, in the north and also elsewhere (e.g., wintering range of migratory species).

Harassment of wildlife, by industrial noise and by low-flying aircraft.

Assessment of National-scale Stressors in the Northern Region

Stressors that are important over the national scale include: long-range transported pollutants (aquatic and atmospheric transport), stratospheric ozone and UV-b, and climate change.

Workshop Group 1 evaluated the importance of these stressors for five ecozones of the Northwest Territories: Arctic Marine, High Arctic (including the arctic islands), Low Arctic, Taiga Plains, Taiga Shield; and also the Mackenzie River (excluding the terrestrial part of its watershed). The results are shown in the table below.

Qualitative assessment of the importance of selected stressors in the five ecozones, and the Mackenzie River, of the Northwest Territories. A score of 0 indicates a trivial importance, 1 indicates some concern, especially for the future, and 2 indicates a more major, present concern; * indicates that the stressor is potentially important.

	Ecozone					
	Arctic Marine	High Arctic	Low Arctic	Taiga Plains	Taiga Shield	MacKenzie River
LRTAP						
- trace toxics	2	2*	2*	2*	2*	2*
- acid rain	0	0	0	0	0	0
- radionuclides	0	1	1	1	1	0
- haze	1	2	1	0	0	0
LRTAqP						
- pulp-mill effluent	0	0	0	1-2	1-2	1-2
- trace toxics	1	0	0	1	1	1
- oceanic toxics	2	1	1	1	1	1
Stratospheric O ₃ and UV-b	2*	2*	2*	2*	2*	2*
Climate Change	2	2	2	2	2	2

Assessment of Regional-scale Stressors in the Northern Region

Workshop group 2 focused on extensive-monitoring of stressors related to resource development (minerals, and oil and gas), wildlife exploitation (hunting, fishing, and trapping), and human population growth and tourism. The table below reports the assessment of Group 2 regarding the importance of these stressors in the five ecozones represented in the NWT. A score of 0 indicates a trivial importance, while 1 indicates some concern, especially for the future, and 2 indicates a more major, present concern:

Stressors	Arctic Marine	High Arctic	Low Arctic	Taiga Plain	Taiga Shield
Mining					
exploration	0	2	2	2	2
production	2	2	2	2	2
Oil and Gas					
exploration	2	2	2	2	0
production	2	2	2	2	0
Transportation	2	2	2	2	2
Hunting	2	2	2	2	2
Fishing	2	2	2	2	2
Trapping	0	2	2	2	2
Tourism	1	2	1	2	1
Population Growth	1	1	1	2	1

Prairie Region

Participants in the Prairie Region workshop prepared a list of the important stressors affecting the Prairie Region, with an emphasis on prairie habitats. This list includes the following:

Climate change, occurring naturally or forced by human activities (e.g., by enhancement of the greenhouse effect as a result of the emission of radiatively active gases to the atmosphere). Specific stressors are temperature, moisture, wind, and insolation.

Stratospheric ozone and enhanced flux of biologically damaging **ultraviolet-B radiation**.

Tropospheric pollutants, including ozone and other photochemical oxidants, other toxic gases such as SO₂ and NO_x, dust deposition, and trace toxics such as metals and pesticides.

Dust loading.

Agriculture. (See next section for a detailed list of agricultural stressors.)

Eutrophication.

Commercial fishery, especially in the Manitoba Great Lakes.

Forestry.

Hydrological manipulations, including hydro-electric development, impoundments, moving or removing waterbodies or water courses, changing drainages.

Potash mining.

Oil and gas exploration and resource development.

Ecosystem conversion associated with a number of stressors, including the conversion of natural ecosystems to agroecosystems, to urban lands, to plantation forests, or to hydroelectric reservoirs.

Habitat fragmentation.

Waste disposal, including solid wastes, sewage, and toxic wastes.

Introduced species of plants, animals, and pathogenic microorganisms (such as those that can cause certain wildlife diseases).

Recreation, including consumptive activities such as hunting and fishing, and non-consumptive activities, such as hiking, camping, and boating.

Increased access to remote areas through roads and designated transmission corridors, which can greatly increase stresses associated with hunting, fishing, and other activities.

Stressors Related to Agriculture in the Prairie Region

Workshop Group 1 focused on agricultural systems and developed the following list of stressors related to agriculture (** denotes those stressors thought to be especially important):

Soil erosion by wind and water.

Cultivation (special attention on practice of summerfallowing which occurs on 25 M acres/yr on the prairies).**

Pesticide use.**

Fertilizer use.**

Disposal of manure from domestic livestock.

Disposal of solid and liquid wastes from food-processing industries.

Grazing by domestic livestock in natural and semi-natural ecosystems.**

Hydrologic modification, including irrigation, drainage, aquifer depletion, and consolidation of ponds.**

Salinization, a secondary stressor that can develop as a result of irrigation and summerfallowing.

Introductions of exotics, including weedy plants, and perhaps non-native species of ungulates for game farming.

Harassment of wild species, including visual and aural disturbance by machinery, control of wild predators, and enhanced access to natural habitats.

Conversion, including the conversion of natural and semi-natural ecosystems to agroecosystems, and the conversion of productive agroecosystems to an urban or industrial land-use.

Inappropriate land use, i.e. the use of crops or cropping systems that are inappropriate to the ecological and other characteristics of the site or region in terms of the longer-term sustainability of the system, including policies, subsidies, and other components of the decision-making system that encourage inappropriate land use.**

Stressors Affecting Aquatic Environments in the Prairie Region

For extensive monitoring of the aquatic environment, Group 2 identified four types of aquatic systems: lacustrine, riverine, intermittent (including potholes and marshes), and groundwater. The relative importance of different stressors for each type of aquatic system was evaluated as follows: 1 -- very important, 2 -- important, 3 -- unimportant, 4 -- potentially important; and * -- localized effects only. This information is summarized in the table below:

Stressor	Lacustrine	Riverine	Intermittent	Groundwater
Nutrients	1	1	1	2*
Pesticides/ Other toxics	1	1	1	1
Industrial/Municipal discharge	1	1	1	2*
Landfill	3	3	2*	2*
Road access	2*	2	2	3
Urbanization	2	1	2	1
Industrial/Municipal consumption	2*	1	3	1
Dams/Impoundments	1	1	1	2
Irrigation	1	1	1	1
Drainage	1	1	1	2*
Erosion	1	1	1	3
Deforestation	2	1	1	3
Fire	3	3	1	3
Exotics	1	1	1	3
Commercial fishing	1	2	3	3
Consumptive recreation (hunting & fishing)	1	1	2	3
Non-consumptive recreation	1	1	2	3
Climate change & variability	1	1	1	1
Atmospheric deposition	4	4	4	3
Ozone depletion	4	4	4	3

ECOLOGICAL INDICATORS FOR EXTENSIVE-MONITORING

Introduction

At the Atlantic, Pacific, Northern and Prairie regional workshops, participants identified and discussed potential indicators for extensive-monitoring within the particular region. The procedure was similar to that described previously for the case study of an intensive monitoring site at Kejimikujik NP (Atlantic Maritime Ecozone). The focus, however, was extended to what could be monitored on the regional-scale. Where possible, the workshop facilitators guided the discussion by maintaining a focus on monitoring for the effects of particular stressors. These lists and descriptions of indicators are summarized for each region in the sections that follow.

Atlantic Region

One of the groups in the Atlantic Region workshop focused on indicators for extensive-monitoring in this region. The indicators identified by the group are listed and discussed below. First are presented exposure indicators, and secondly, response indicators. The availability of indicators are summarized in a table following each annotated list. Comparison of the tables for exposure and response indicators demonstrates the common trend of response indicators being much more deficient than exposure indicators.

Exposure Indicators are those that refer to the rate of change and/or intensity of stressors. A list of exposure indicators for the Atlantic Region would include:

Land Use. The rate of change in land use gives a regional overview of the character of the landscape at different times. Relevant data are available for the Atlantic Maritime ecozone from Environment Canada (Environmental Information Systems, Ecological Land Survey; ref. 2,3 in Spencer and Neumeyer 1989). There are deficiencies about changes in wildlife habitat, largely because there is no systematic methodology within the region to assess habitat or to identify species at risk, especially non-game species (Burnett *et al.* 1989). Although initiatives are beginning at the provincial level (Wellings and Barron 1988). For game species and fur-bearing mammals, provincial and non-governmental wildlife agencies periodically assess habitat (Spencer and Neumeyer 1989).

Changes in the number of roads, housing units, shopping malls, etc. are an indication of the rate of urbanization. The rate of conversion from one ecosystem type to another (e.g., agriculture to forest, wetland to agriculture, natural forest to tree plantation, etc.) offers an overview of changes in the character of the landscape. In the Atlantic Maritime region, 30% of farms were abandoned by 1960, most of which reverted to forests or wetlands (Lands Directorate 1986).

In some areas, natural forests are being converted to intensively managed conifer plantations (related data are in Kuhnke 1989). Environmental issues include sustainability, effects on biodiversity, soil quality, surface waters, and conflicts with other land uses (Freedman 1989).

Area of Bare Soil. Bare soil is at risk to erosion by wind and water. Such areas can be assessed by satellite imagery or air photos, especially before snowcover is established (Environmental Information System ref. 2; Flood Risk Map ref. 39 in Spencer and Neumeyer 1989)

Area or Volume of Solid Waste Disposal. Relevant data are available from municipal governments, and are an indicator of per capita disposal of solid waste.

Industrial Emissions. There is no systematic monitoring of point sources of industrial emissions in the Atlantic Maritime region. However, emissions from certain industrial sites are monitored by industry itself, or by provincial or federal agencies (ATLMON ref. 28; NAQUADAT ref. 47; HYDAT ref. 15 in Spencer and Neumeyer 1989).

LRTAP Indicators.

Precipitation. The chemistry and volume of precipitation is being monitored throughout the region by various agencies (Lake Chemistry Data Base ref. 90; Rain Chemistry Data Base ref. 91, LRTAP ref. 92 in Spencer and Neumeyer 1989).

Air Quality. Concentrations of gaseous atmospheric pollutants are monitored across the region by various agencies (EPS 1989a,b; CaPMoN ref. 101 in Spencer and Neumeyer 1989).

Oxidants. Concentrations of ground-level ozone are monitored at selected sites (by Environment Canada - EPS 1989a,b; CaPMoN ref. 101 in Spencer and Neumeyer 1989).

Environmental Accidents. The numbers of spills of petroleum products, toxic chemicals, and other hazardous substances are an indication of environmental damage from such accidents. Data are routinely compiled by Transport Canada, Environmental Protection Service, and provincial environment agencies. The Transport Dangerous Goods Directorate of Transport Canada publish a newsletter, on a quarterly basis.

Chemical Use: Domestic, Agriculture and Forestry. Data on the types, quantities, and value of the use of fertilizers and pesticides would indicate the risks of these activities. Relevant data for forestry are available from the FORSTATS database (e.g. Kuhnke 1989), but comprehensive data for domestic and agricultural use are not readily accessible.

Forest Management. Environmental effects of forest management are related to the area that is annually treated in various ways. Relevant information includes the area of: forest harvested by various techniques (e.g., clearcut, stripcut, shelterwood, etc.), scarified, replanted with particular species, naturally regenerated, etc. Data are accessible in the FORSTATS database (e.g., Kuhnke 1989).

Ecological Reserves. Ecological reserves by area of habitat type are an index of ecological diversity in reserve. There are deficiencies in the present information, largely because the provinces have not established a methodology to assess biodiversity. However, some relevant data are available from databases of Parks Canada, provincial governments, and the Island Nature Trust in P.E.I. (recently summarized in Hummell 1989).

Habitat Fragmentation. Because some wildlife species require large, contiguous areas of forest, the degree of fragmentation has important implications for biodiversity, an index of ecosystem integrity (e.g., Schindler 1990). Data, though not presently available, could be obtained from aerial photographs.

Habitat Diversity. Wildlife diversity is related to habitat diversity, both of which have been neglected in monitoring programs. Some relevant information can be obtained from Forestry data on "cover type by maturity class." This indicator is an index of the proportion of forested land in different age classes, often by tree species, which reflects habitat availability and diversity. Such information is available from forest inventories (e.g., Kuhnke 1989).

The table below provides a matrix of stressors (horizontal) by exposure indicators (vertical) proposed for extensive monitoring. Each cell indicates whether the data for exposure or response indicators are: available (**A**), of limited availability (**a**), deficient (**D**), or irrelevant to the stressor (-). See text for descriptions of indicators.

Exposure Indicators	Stressors					
	Land Use	Resource Extract.	Industrial Emissions	Climate Change	LRTAP	Natural Disturbance
Land Use	A	A	A	-	-	A
Area of Bare Soil	A	A	-	-	-	a
Solid Waste Disposal	A	-	A	-	-	-
Industrial Emissions	-	-	A	-	-	-
LRTAP Indicators	-	-	a	-	A	-
Environmental Accidents	-	-	A	-	-	-
Pollutant Inputs	-	A	A	A	A	-
Chemical Use	A	A	-	-	-	-
Forest Management	A	A	-	-	-	-
Ecological Reserves	a	A	-	-	-	-
Habitat Diversity	D	a	-	-	-	-
Habitat Fragmentation	a	a	-	-	-	a

Response Indicators are those that refer to the actual response of a system to a stressor. A list of response indicators for the Atlantic Region would include:

Land capability. Land capability is an estimate of the quality of land or freshwater for forestry, agriculture, ungulates, waterfowl, and sportfish (Environmental Information Systems, ref. 2 in Spencer and Neumeyer 1989). Relevant information on soil quality, drainage, topography, etc., is usually obtained using air photos, satellite imagery, and hydrological data.

Inland Waters.

Fish community. Changes in the distribution and abundance of fish can indicate changes in water quality (although the relationship is obscured in areas of intense fishing activity). However, presence or absence of species can indicate state of the environment. For example, salmonids do not occur in highly acidic waters in the Atlantic Maritime region (Watt *et al.* 1983; Environment Canada 1988).

Fish health. The occurrence of fish diseases is routinely monitored throughout the Atlantic Maritime region (Fish Health Data Base, ref. 17 in Spencer and Neumeyer 1989).

Aquatic birds and other biota. Canadian Wildlife Service and provincial agencies regularly census waterfowl throughout the Atlantic Maritime ecozone (National Harvest Surveys, ref. 66 in Spencer and Neumeyer 1989). Some information is also available for other aquatic biota (Nutrient and Biological Productivity in Atlantic Region Waters, ref. 46 in Spencer and Neumeyer 1989).

Water chemistry. Changes in water chemistry (e.g. pH, major ions, nutrients, dissolved oxygen, metals, etc.) can indicate: i) habitat quality, ii) effects of atmospheric deposition, and iii) effects of land use in the watershed (Freedman 1989; Hartman and Scrivener 1990). Water chemistry is thoroughly monitored in the Atlantic Maritime by federal and provincial agencies (Howell 1986; references in Spencer and Neumeyer 1989).

Wetlands.

Water chemistry and biota. Baseline inventories of water chemistry, vegetation, and animal species have been made by Canadian Wildlife Service to identify wetlands important to waterfowl (Maritime Wetlands Inventory, ref. 85 in Spencer and Neumeyer 1989). However, wetlands unsuitable for waterfowl (especially peatlands) are not as well surveyed (Manuel 1987).

Forests. Forest inventories and silvicultural data are available from provincial agencies and Forestry Canada (FORSTATS database, recently summarized in Kuhnke 1989). Especially relevant indicators include:

Productivity. Forest productivity indicates the net increment in merchantable biomass.

Forest community by site. Forest community measures that indicate habitat diversity are mostly deficient, except for tree data, which are broadly available.

Age-class distribution. This indicator reveals the amount and diversity of clearcuts, and young, mid-successional, and old-growth habitat.

Pest and disease incidence and forest decline. The abundance and distribution of injurious forest insects and tree diseases are routinely monitored by Forestry Canada (e.g., Magasi 1990). Possible effects on trees of LRTAP are being monitored through the Acid Rain National Early Warning System (ARNEWS; Magasi 1988). For example, near the Bay of Fundy, leaf browning has been correlated with fogwater acidity and nitrate, and possibly ozone (Cox *et al.* 1989).

Soil quality. Data relevant to changes in forest soil quality (organic matter, acidity, nutrient availability, soil biota, etc.) are not available on a regional scale. Some monitoring data are available from ARNEWS (Magasi 1988), and provincial agencies categorize some soil characteristics on forest inventory plots (E. Bailey, Nova Scotia Department of Lands and Forests, pers. comm.). However, there is no longer-term, regional monitoring of the effects of LRTAP and intensive harvesting and management on soil quality.

Non-economic indicators. Prominent in this category are the species composition and abundance of non-game animals and non-commercial vegetation, as well as habitat indicators (e.g., snag size and density, logs-on-the-ground, vertical profiles of foliage and habitat mosaic, etc.). Few data are available on a regional scale.

Agriculture. Agricultural systems are monitored in a relatively extensive program. Data are available from Agriculture Canada or Statistics Canada. Especially relevant indicators include:

Production. Changes in the productivity of crop species, or in area planted, may indicate a response to stressors (although changes in crop area may also occur in response to economics). For example, certain species are relatively susceptible to pollutants (e.g., some varieties of tobacco are hypersensitive to ozone).

Soil Quality. The quality of agricultural lands across Canada will be monitored by the National Soil Quality Evaluation Program (K. Webb, Agriculture Canada, pers. comm.). The program is in a pilot phase, but when fully operational it will report on a regional scale.

Crop damage. The loss of crops to inclement weather, insects, disease is routinely monitored by provincial and federal agencies.

Wildlife.

Rare and endangered species. The distribution and abundance of selected species are monitored by provincial wildlife agencies and the Canadian Wildlife Service, in

conjunction with non-governmental organizations such as the World Wildlife Fund. However, not all rare and endangered species are being investigated (Burnett *et al.* 1989).

Game species. The abundance of game species is routinely monitored by provincial wildlife agencies, and the data are readily available.

Non-game species. As noted earlier, there are very few data on non-game species. A comprehensive monitoring program requires baseline inventories of major taxa. For non-game birds, which are relatively well studied, there are three relevant sources of information: (i) the Breeding Bird Survey, (ii) the Christmas Bird Count, and (iii) the Breeding Bird Atlas. However, in some respects the quality and usefulness of the data for SOE monitoring are questionable. Another source of potential regional information are bird observatories located on major migration routes, such as the Long Point Bird Observatory in southern Ontario (Hussell *et al.* 1990).

Habitat diversity. Landscape changes affect wildlife diversity, by affecting the diversity of habitats. Ultimately, management for diversity of habitats may be easier than trying to attain population goals for all species. For example, intensive forest management affects habitats greatly, and this could be monitored across forest types through succession. The stand types could include a range of managed forests, with various types of harvest (e.g., clear-cut, selection cut) and silvicultural practices (e.g., scarify, herbicide, etc.), and with undisturbed forest as a reference. Since 1988, the Canadian Wildlife Service has been monitoring bird populations in habitats subjected to intensive forest management in New Brunswick (Forest Bird Habitat Requirements, ref. 19 in Spencer and Neumeyer 1989). The loss of other specific habitats over time could be measured using data from the Canadian Land Inventory (Environmental Information Systems, ref.2 in Spencer and Neumeyer 1989).

Below is shown the matrix of stressors (horizontal) by response indicators (vertical) proposed for extensive-monitoring in the Atlantic Maritime ecozone. Each cell indicates whether the data for indicators are: available (**A**), of limited availability (**a**), deficient (**D**), or irrelevant to the stressor (-). See text for descriptions of indicators.

Indicator	Stressors					
	Land Use	Resource Extract.	Industrial Emissions	Climate Change	LRTAP	Natural Disturbance
Land Capability	A	A	-	-	-	a
Inland Waters						
Fish community	-	A	A	-	A	-
Fish health	-	A	A	-	A	-
Aquatic birds, biota	-	-	-	-	a	-
Water chemistry	A	A	a	-	A	-
Wetlands						
Water chemistry, biota (baseline inventory)	-	a	-	-	-	-
Forests						
Productivity	-	A	-	D	D	-
Forest community	A	A	-	D	A	-
Age-class distribution	A	A	-	-	-	-
Pest incidence, Forest decline	-	A	-	-	-	-
Soil quality	-	a	-	-	A	-
Non-economic indicators	D	D	-	D	D	-
Agriculture						
Production	-	A	-	D	D	-
Soil quality	-	a	-	-	a	-
Wildlife						
Endangered species	a	a	-	D	D	-
Diversity - game species	a	a	-	D	D	-
Diversity - non-game	D	D	-	D	D	-
Habitat diversity	D	D	-	D	D	-

Pacific Region

In the Pacific Region workshop, one group of participants identified indicators for several major stressors affecting B.C. The other groups of participants used a case-study approach to illustrate a process that could be used to identify suitable indicators of exposure or response to environmental stressors in British Columbia. These indicators were considered to be "desirable" from the environmental monitoring perspective; **consideration was not made as to whether information was currently available, or whether it would be operationally practical to develop extensive indicators of the types identified.** In some respects, the lists represent "wish lists" of indicators of extensive-monitoring programs. Results of the three group discussions are summarized below.

Indicators of Major Stressors Affecting B.C.

In a previous section of this document, six major stressors were identified for B.C. In most cases, indicators of these stressors were selected on the basis of their current availability, although indicators for which data are deficient were also noted. Due to time limitations, indicators of stressors (5) and (6) were not identified. Indicators of stressors (1) to (4) were:

1) Land Use

(a) **Actual Forest Cut/Long-range Sustained Yield.** This ratio determines whether the amount of forest cut is more than is available over the longer term. The question arose as to whether the data for Long-Range Sustained Yield (LRSY) were available to complete the ratio. It was felt that the data were deficient in the sense that the methods used to calculate LRSY were questionable as well as variable among regions.

(b) **Protected Land vs. Total Land Base.** The information is available, but it was questioned whether this was a better indicator of government action rather than a good indicator of ecosystem health. Additional indicators are needed including:

- (i) **Conversion of Land Base to Managed Monoculture of lesser Diversity**, e.g. grassland and silvicultural practices.
- (ii) **Conversion of Agricultural to Residential Land**, i.e. urbanization.

(c) **Threatened and Endangered Species by Ecozone.** This information is available and useful, although it is not complete for all taxa.

(d) **Biodiversity.** This information is not readily available, but would be very useful. As it is a difficult indicator to monitor, it was felt that biodiversity was a good candidate for study at Intensive-Monitoring sites. In general, potential indicators include the amount of old-growth and mature forest by biogeoclimatic zone, species abundance of soil micro-organisms, abundance of endemic and rare species, etc.

2) Fresh Water

(a) **Total Phosphorus/Spring Overturn Phosphorus.** This is a measure of the trophic status of lakes, indicated by phosphorus cycling.

(b) **Watersheds Not Attaining Water-Quality Objectives.** Objectives for water quality are not established for all allocated uses, and participants therefore agreed that this was best considered as a candidate indicator for intensive-monitoring.

(c) **Groundwater Aquifers Not Attaining Drinking Water Standards.**

(d) **Watershed Areas with Affected Fish Health.** In particular, areas with declining, absent, or contaminated fishstocks should be reported.

(e) **Watershed Areas with Adverse Changes.** In particular, deleterious changes in flow regime, transported sediment, and organic loadings.

3) Marine

(a) **Non-use of Marine Resources, Due to Contamination or Depletion of Marine Foreshore and Shelf Stocks.**

(b) **Toxic Contamination of Marine Mammals and/or Estuarine Ground Fish and Shellfish.**

(c) **Foreshore and Nearshore Areas affected by Woodwaste from Log Booms.** There was some question as to the availability of information relevant to this indicator.

(d) **Toxic Contamination of Seabird Eggs.**

4) Air

(a) **Number of Acute Toxicity Incidents and Long-term Effects of Air Pollution on Human Health.** It was noted that the incidence of human respiratory diseases could not be firmly related to particular air pollutants, although in some cases strong inferences have been made based on epidemiological information.

(b) **Number of Exceedences of Federal Ambient Air Quality Objectives, or Number of Exceedences of Health Alert Concentrations.** For example, concentration of ground-level ozone during the summer in Vancouver.

(c) **Acidity of Lakes and Condition of Forests.** This information is available through the Long-range Transported Air Pollutant monitoring program (LRTAP) and Acid Rain National Early Warning System (ARNEWS), although these programs address forest conditions more than the acidity of surface waters.

(d) **Total Emission of Greenhouse Gases.** For example, rates of emission or budgets of carbon dioxide, methane, CFCs etc.

Indicators for Coastal Zone Management in the Pacific Region

One workshop group developed a list of indicators of exposure and response to two selected stressors (oil tanker traffic and recreation) related to Coast Zone Management. This list is presented below. In regards to indicator availability, **A** indicates that useful monitoring data are presently available; **a** indicates that some data are available, but there are deficiencies; **D** indicates that relevant monitoring data are not presently available.

Indicators	Availability
------------	--------------

Oil Tanker Traffic

- | | |
|--|---|
| - total vessels, total tonnage, hull type | A |
| - reported spill frequency and size | A |
| - beach surveys for tarballs and oiled birds | a |
| - hydrocarbon bioaccumulation in shellfish | D |

Recreation

- | | |
|--|---|
| - operator type and capacity | A |
| - visitor surveys | A |
| - aerial surveys of recreational vessels | a |
| - sportfish and shellfish harvesting | A |
| - recreational salmon harvest/escapement
or harvest/stock size | a |
| - area closed to shellfish harvesting | A |
| - beach closings due to high coliforms | A |
| - beach surveys for persistent litter | D |
| - census of resident and transient orcas,
sea lions, gray whales, harbour seals | a |
| - landscape aesthetics | D |

Indicators of Effects of Forestry Practices in B.C.

The following case study dealt with indicators useful for environmental monitoring of three generic suites of activities associated with forestry. Activities are harvesting, silviculture, and manufacturing. The matrix resulting from this exercise is described in the following table. Note that the working group did not endorse the use of only **a single indicator of forestry**. There is a need for indicators of various aspects of the forest, especially those relating to conventionally non-economic values. **If the group was forced to select a single indicator, however, area regenerated/area harvested would be selected as an appropriate indicator of the economic-forest resource** (as was used in a recent SOE report (Anon. 1991)). The following table summarizes the indicators identified and their present availability.

Matrix of exposure and response indicators for extensive-monitoring of generic stressors associated with **forestry** in British Columbia. **Harvesting** refers to activities associated with clearcutting, shelterwood cutting, selection cutting, merchantable thinning, etc.; **Silviculture** refers to site preparation by prescribed fire or mechanical methods, silvicultural use of herbicides, premerchantable thinning, etc.; **Manufacturing** refers to activities associated with the production of pulp or paper, the manufacture of lumber or composite products, etc.; **Availability** refers to the present state of availability of the indicator; **X** indicates that the indicator is believed to be of potential utility for extensive-monitoring purposes; **0** indicates that the indicator is not relevant; **A** indicates that useful monitoring data are presently available; **a** indicates that some data are available, but there are deficiencies; **D** indicates that relevant monitoring data are not presently available.

Forestry Activity as a Stressor

Indicators	Harvesting	Silviculture	Manufacturing	Availability
<u>Aquatic</u>				
- hydrology (flow, peaking)	X	X	X	a
- turbidity	X	X	X	a
- water quality objectives	X	X	X	a
- habitat quantity and quality	X	X	X	a
- fish abundance	X	X	X	a
- invertebrate community	X	X	X	D
- biochemical, fish liver MFOs	0	0	X	D
<u>Terrestrial</u>				
- old-growth forest depletion account	X	X	0	a
- area regenerated/area harvested	X	X	0	A
- NSR (not satisfactorily restocked) account	X	X	0	A
- area harvested by method	X	0	0	A
- wood waste compliance	X	X	0	a
- MAI (mean annual increment) stratified by site class	X	X	0	A
- projected MSY (maximum sustainable yield) in the ecozone	X	X	0	A

Matrix of exposure and response indicators for extensive-monitoring of generic stressors associated with **forestry** in British Columbia (table continued):

Indicators	Forestry Activity as a Stressor			
	Harvesting	Silviculture	Manufacturing	Availability
Terrestrial (cont'd)				
- site class degradation				
- depleted production of site	X	X	0	a
- area lost to roads and landings	X	0	0	D
- age-class and community-type projections	X	X	0	D
- habitat				
- patchiness and dynamics	X	X	0	D
- insularization	X	X	0	D
- furbearer abundance	X	X	X	a
- ungulate abundance	X	X	X	a
- selected indicator species of endangered habitat	X	X	X	D
- periodic forest CO ₂ budget	X	X	X	a
- pesticide use	0	X	X	A
- bioaccumulation of TCDD, chlorophenolics	0	X	X	A
- atmospheric pollutants				
- total reduced S in air	0	0	X	A
- SO ₂ , NO _x , organics, inorganic aerosols	0	0	X	a
- smoke				
- from site preparation	0	X	0	a
- residue burning at mills	0	0	X	A
- landscape aesthetics	X	X	X	D

Northern Region – Indicators for Extensive-Monitoring of National-scale Stressors

Participants in the Northern Region workshop Group 1 identified candidate lists of indicators that were considered necessary for a comprehensive environmental monitoring program for the selected stressors. The availability of indicators was also evaluated: **A** indicates that useful monitoring data are presently available for the indicator; **a** indicates that some data are available, but there are deficiencies in the database; and **D** indicates that relevant monitoring data are not presently available, or that the indicator is not well-developed. An **X** indicates that the indicator is relevant to the stressor.

(1) **Trace Toxics.** Trace toxics include inorganics such as mercury, lead, cadmium, and arsenic, and organohalines such as PCBs, DDT and other chlorinated pesticides, and dioxins and furans. The following indicators of contamination (i.e., exposure) were suggested (all of which are presently [**D-a**]):

Indicators	<u>Extensive</u>	<u>Intensive</u>
- precipitation chemistry		
- accumulated snowpack	X	X
- events		X
- lichen chemistry	X	X
- ringed seal (or perhaps beluga)*	X	
- char or lake trout*	X	
- wolf or mink (long-lived terrestrial carnivore)*	X	
- caribou*	X	

* wherever possible, tissues would be collected from animals that were killed by hunters.

For some microchemical analyses in which the risk of inadvertent contamination may be an overwhelming consideration, this may not be possible.

(2) **Depletion of Stratospheric Ozone.** The next stressor considered by the group was depletion of stratospheric ozone, and the resultant increase of irradiation with ultraviolet-B at ground level. The group felt that this stressor could be dealt with using relatively few indicators.

Exposure indicators

- flux of ultraviolet radiation [**a**] - measured using UV-b and total-UV radiometers, with continuous measurement at the existing (or expanded) network of climate stations.
- ozone in the stratosphere [**a**] - monitored from the ground by remote sensing, monthly (?) at 1-3 sites in northern region, and supplemented by measurements made within the stratosphere by high-altitude flights using aircraft or balloon.

Response indicators

- extensive-monitoring

- epidemiological studies of human skin cancers and cataracts [a]. Incidence of occurrence of cataracts might also be monitored in some wide-ranging species of large-game animals, such as caribou or muskox [D].

- intensive-monitoring

- plant pigments, especially chlorophylls, and their ratios in selected wide-ranging species [D].
- phytoplankton pigments and their ratios [D], and also changes in phytoplankton community structure [D].
- plant production in permanent plots [D], even though this would not be a very specific indicator of response to enhanced exposure to ultraviolet radiation.

(3) **Climate Change.** The working group then focused on climate change, a much more complex stressor than trace toxics and stratospheric ozone, and therefore requiring a more diverse assemblage of indicators of exposure and response. Initially, relatively long lists of indicators were identified as being necessary for appropriate monitoring of exposure and response to climate change. Later in the workshop, indicators were ranked in importance to produce a short-list of extensive and intensive indicators, that would constitute a minimal suite of indicators.

The longer-list of **indicators of exposure and response** to climate change is shown below. Also given are potential suitability of the indicator for intensive- and/or extensive-monitoring, and whether relevant information is presently available (note that for the climate-related indicators, the identified deficiencies are mostly related to an inadequate network of climate-monitoring sites, as opposed to an incomplete collection of data at existing sites):

<u>Exposure Indicators</u>	<u>Extensive</u>	<u>Intensive</u>	<u>Availability</u>
Concentrations of atmospheric CO ₂ and other radiatively-active gases	X		A
Air temperature (at 1 m) ([a] for the Mackenzie River corridor)	X	X	D
Soil temperature	X	X	D
Growing degree-days	X	X	D
Thawing degree-days	X	X	D
Precipitation volume	X	X	D
Precipitation as snow or rain	X	X	D
Precipitation intensity	X	X	D
Dates of snowcover in & out	X	X	a
Lake-ice in & out	X	X	a
Sea-ice in & out	X	X	A

<u>Exposure Indicators</u>	<u>Extensive</u>	<u>Intensive</u>	<u>Availability</u>
Glacial-ice temperature	X	X	D
Large-lake temperature	X	X	D
Active-layer depth	X	X	D

Response Indicators

Aquatic - physical/chemical

- lake levels	X	X	D
- hydrology			
- discharge volume	X	X	a
- timing of events	X	X	a
- suspended inorganics	X	X	D
- marine salinity		X	D

Aquatic - biological

- fish			
- distribution	X		D
- community		X	D
- phytoplankton - community		X	D
- phytoplankton - production		X	D
- zooplankton		X	D
- benthic invertebrates		X	D
- palynology and paleo-ecosystems	X		a
- sediment-diatom reconstructions	X		D

Terrestrial - physical/chemical

- glaciers			
- movement of fronts	X	X	a
- mass balance		X	D
- flux of greenhouse gases from peatlands		X	D

Terrestrial - biological

- tree-line dynamics	X	X	a
- plant community in permanent plots		X	D
- plant phenology in permanent plots		X	D
- plant biomass		X	D
- retrospective tree-ring analysis	X	X	D
- populations of "economic" wildlife	X	X	A
- phenology of migratory animals	X	X	a
- arthropod community & abundance		X	D

It is unlikely that all of the indicators suggested above could actually be monitored extensively, because of probable constraints on monitoring programs. The workshop subgroup thus produced a short-list of **extensive and intensive indicators** that might constitute a minimal suite of indicators for monitoring effects of climate-related changes in northern Canada. Consideration was also made of whether the indicator has a capability of measurement by remote instrumentation (**RI**), by remote sensing or surveillance (**RS**), or whether it would require site visits (**SV**). This list follows:

<u>Indicator</u>	<u>Extensive</u>	<u>Intensive</u>
Non-glacial hydrology		
- quantity and timing (RI)	X	X
- rivers and lake levels (RI)	X	X
Soil temperature profile (RI)	X	X
Air temperature (RI)	X	X
Sea-ice distribution (RS)	X	
Snow cover (RS)	X	X
Glacier movement (RS)	X	X
Tree-line dynamics, ecotones	X (RS)	X (SV)
Plant phenology (SV)		X
Fish distribution (SV)	X	
Animal phenology (SV ; aerial survey)	X	X

Indicators for Extensive-Monitoring of Regional-scale Stressors

Workshop Group 2 identified indicators suitable for measuring the effects of stressors that are more directly related to human impacts in the Northern Region, particularly the NWT. Group 2 also evaluated the availability of data relevant to these indicators. Two matrices were prepared, as shown below. The first matrix addresses monitoring for stressors related to resource development, and the second matrix addresses monitoring for other stressors. Population growth was not addressed specifically because its current impact is primarily socio-economic.

In the matrices below, the relevance of the proposed indicator to the stressor is noted (**X**: relevant; **0**: not relevant; **P**: potentially relevant). The availability of indicators was also evaluated (**A**: indicator well-developed and database available; **a**: indicator developed but database deficient; **D**: indicator is not developed).

Indicators proposed for monitoring the effects of resource development (expl.: exploration; prod.: production) in the Northern Region were:

Indicators	Stressors				Availability
	Mining		Oil and gas		
	Expl.	Prod.	Expl.	Prod.	
Atmospheric					
emission levels	0	X	P	X	D
types	0	X	P	X	D
extent	0	X	P	X	D
Freshwater					
water					
quality	X	X	X	X	a - D
quantity	0	X	0	X	A - a
suspended sediment	0	X	0	X	D
biota					
phytoplankton	P	X	P	X	D
zooplankton	P	X	P	X	D
macrophytes	P	X	P	X	D
invertebrates	P	X	P	X	D
fish	P	X	P	X	D
birds	P	X	P	X	a
Terrestrial					
habitat	P	X	P	X	a - D
plant species	P*	X	P	X	D
wildlife					
amphibians	P	X	P	X	D
small mammals	P	X	P	X	D
birds (raptors)	P(X)	X	P(X)	X	a
ungulates	P	X	P	X	A - a
furbearers	P	X	P	X	A - a
large predators	X	X	X	X	a

* if rare or endangered

Indicators proposed for monitoring the effects of hunting, fishing, trapping, and tourism in the Northern Region were as follows:

Indicator	Stressors				Indicator Availability
	Hunting	Fishing	Trapping	Tourism	
fish abundance:harvest ratio	0	X	0	X	A
fish community structure	0	X	0	X	a
migratory marine mammals	X	P	0	P	a
furbearers harvest	0	0	X	0	A
ungulates -- Caribou	X	0	0	0	A
time budgets of animals	0	0	0	X	D
birds -- raptors	0	0	0	X	a
distribution of animals	0	0	0	X	a
tourist activity patterns	P	P	0	X	A

Most of the indicators listed above are rather general, and some refer mainly to types of animals that should be monitored. The following list was compiled of more specific indicators that could be extensively monitored for some of the above species (where relevant):

<u>Indicator</u>	<u>Availability</u>
numbers harvested	A
migration patterns and timing	A
population size and variability	a
health of individuals	a
hunting effort	
recreational hunting	a
subsistence hunting	D
sex and age structure, and variability thereof	D

Prairie Region

Participants in the Prairie Region workshop separated into three groups to discuss indicators for extensive-monitoring in the region. Each group focused on one of the following: agricultural systems, and aquatic ecosystems, and climate change. The lists of indicators developed by each group are summarized in the following three sections.

Indicators for Agricultural Systems in the Prairie Region

Participants in one group identified candidate lists of exposure indicators that were considered useful for a comprehensive environmental monitoring program for the short-list of agricultural stressors. Certain of the indicators are rather specific to particular stressors, while other indicators are more general and are relevant to the complex of stressor activities associated with cropping systems. Consideration was also made as to whether monitoring information was already available for the proposed indicators. Note that in the following, [A] indicates that useful monitoring data are presently available; [a] indicates that some data are available, but there are deficiencies; [D] indicates that relevant monitoring data are not presently available.

Indicators of Exposure to Agricultural Stressors

Pesticide Sales [A?]. This would be a specific indicator of regional pesticide use, and also perhaps an indicator related to inappropriate land use.

Pesticide Residues [A-a] in foodstuffs would be an appropriate indicator of exposure of crops to relatively persistent pesticides. (See also section on Integrated Monitoring for the Effects of Pesticides.)

Fertilizer Sales [A?]. This would be a specific indicator of regional fertilizer use.

Livestock Population (excluding feedlots) [A]. This would be a specific indicator of grazing as an agricultural stressor, and also perhaps an indicator related to inappropriate land use. This could also be an indicator of integrated crop-livestock operations, which in most cases are less harmful to the environment. (**Animal-Unit Months** was identified as an alternative indicator, but data are only presently available [A] for leased lands.)

Diversity of Animal/Crop Farming Enterprises [A]. Greater diversity would indicate more opportunities for environmentally benign approaches.

Crop Diversity [a]. This indicator relates to the diversity of cultivars (related to within-species germplasm diversity) and species being cultivated. This is a non-specific indicator, related to cropping systems.

Crop Production [A]. These data would be reported by category in terms of species and, if possible, cropping system (see also Agricultural Cover, below). These are indicators of cropping systems.

Agricultural Cover (land use) [A-a by census information; a-D by remote sensing technology]. These are indicators of cropping systems. The most prominent indicator categories of agricultural cover were considered to be:

- annual vs. perennial cropping systems;
- small grains (wheat, barley, rye) and oil seeds (canola), row crops (sugar beet, potato, vegetables, soybean, sunflower), forage crops (alfalfa, haying systems), fallow; and
- stratify by conservation vs. conventional tillage systems, and by irrigated vs. non-irrigated systems.

Natural Cover (land use) [a-A]. This was considered to be an "inverse" indicator of exposure to agricultural stressors, so that a decrease in natural-cover types would indicate an increase in the extent of agricultural stressors. For these purposes, the most important categories of natural land use (within the biogeoclimatic zone of prairie Canada in which agriculture is a prominent activity) were considered to be:

- tall-grass prairie, mixed-grass prairie, fescue prairie, short-grass prairie, mixed-wood forest, aspen parkland, riparian forest, dunelands, and wetlands, especially pothole ponds, marshes, and lakes.

Landscape Patterns [a] are relevant to the spatial diversity of ecological units in the region, and would be broad indicators of a complex of agricultural stressors.

Indicators of Response to Agricultural Stressors

Response indicators were then developed for the short-list of agricultural stressors. Two classes of indicators were discussed, related to sustainability of: (1) the agricultural system itself, and (2) the natural, ecological heritage of prairie Canada. These are summarized below.

(1) Response Indicators for Sustainability of Agricultural Systems

Yield (per unit area)[a-D] is a non-specific indicator of changes associated with crops and cropping systems. Relevant data should be stratified by crop and cropping system. The participants felt that baseline information is available and reasonably good [a], but there are important deficiencies in existing monitoring programs [D].

Soil [a-D] indicators tend to be rather non-specific indicators of changes associated with crops and cropping systems. Relevant soil indicators include: depth and profile

development, organic concentration, conductivity, pH, waterholding capacity, soil structure and texture, soil fauna, microbial activity. These indicators should be stratified by crop and cropping system. Baseline information is available and reasonably good [a], for example through Agriculture Canada's "National Soil Quality Evaluation Program." However, there are important deficiencies in existing monitoring programs [D], except perhaps for predictive models of changes in soil quality under particular crop and cropping system scenarios [a].

Pest Problems [A-a] could be monitored in terms of the extent and intensity of infestation by weeds, insects, other arthropods, and diseases. These would be fairly specific indicators relevant to pesticide use, cultivation practices, and perhaps grazing, fertilizer use, and inappropriate land use.

Standing Crop of Plants [a] on pastures and rangelands would be an appropriate indicator of grazing as a stressor, and of certain types of inappropriate land use. Extensive-monitoring might be feasible through infra-red remote sensing.

Surfacewater Hydrology and Quality [A] would be rather non-specific indicators of changes associated with crops and cropping systems.

Groundwater Hydrology and Quality [a] would also be non-specific indicators of changes associated with crops and cropping systems.

Energy Efficiency and Nutrient-use Efficiency [D] are composite indices that relate to the sustainability of cropping systems.

Integration of Crop and Livestock Production [a]. An integrated agricultural system, where the same acreage was devoted to crops and livestock, would be more sustainable than either of the two food production schemes alone.

(2) Response Indicators for Sustainability of Ecological Heritage

Protected Areas [A-a], in terms of the area and completeness of the system (i.e., sufficient representation of sufficiently large reserves of all ecosystem types) would be a suitable composite index of ecological integrity in the region of prairie Canada that is developed for agricultural purposes.

Populations of Wildlife could be monitored extensively using indicator species for prominent or otherwise important ecosystem types. For game species, some data are presently collected by wildlife agencies for the purposes of setting bag limits [a-D]. Some species might be at particular risk from certain agricultural stressors or cropping systems, and their status could therefore represent a rather specific indicator. Examples of species nominated during the workshop are:

- **Large mammals** such as white-tailed deer, mule deer, antelope, elk, black bear, wolf, or coyote, depending on ecosystem type.

- **Upland game birds** such as ruffed grouse or sharp-tailed grouse.
- **Waterfowl [a-A]** such as selected species of dabbling and diving ducks. Data are collected co-operatively by Canadian and U.S. wildlife agencies and Ducks Unlimited, to set bag limits and to gauge the success of habitat enhancement programs.
- **Non-game wildlife** including:
 - **Birds of prey [a-D]** such as burrowing owl, red-tailed hawk, golden eagle, marsh hawk, ferruginous hawk, and prairie falcon for prairie habitats, and great horned owl and goshawk for forested habitats.
 - **Songbirds [a-D]** of various species, guilds, or communities could be monitored. Some extensive data are available from the Breeding-bird Survey and the Christmas Count (for wintering birds). Species that would be indicators of certain types of agricultural habitat include crow, magpie, and starling.
 - **Status of rare and endangered species [a-D]** that may be specifically threatened by certain agricultural practices or land-use conversions could be monitored. Fairly good data are currently available for selected species, e.g. burrowing owl, loggerhead shrike.

Extensive Indicators for Aquatic Ecosystems in the Prairie Region

Workshop Group 2 discussed stressors affecting aquatic ecosystems in the Prairie Region. Indicators for extensive-monitoring of the most-important stressors were identified and their availability was evaluated. The notation for indicator availability was as follows: **A** -- information available, **a** -- some information available, **D** -- information not available, and often, indicator requires further development. This information is shown in the following tables of exposure and response indicators. Most of the extensive indicators that were selected as the most important ones to measure (*) are exposure indicators, because their relationships to the stressors are relatively better understood. Further study of response indicators is required before appropriate indicators are selected for use in extensive-monitoring.

1. Pesticides and other toxic chemicals

<u>STRESSOR and EXPOSURE INDICATORS</u>	<u>Availability</u>
application rate (from pesticide surveys)	A
concentrations of chemical:	
* - in water	a
* - in surface sediment	a
- in air	D
* - in predatory fish	a
* - in predatory birds	a
<u>RESPONSE INDICATORS</u>	
sub-lethal effects (on growth, reproduction, or behaviour)	D
mortality	a
<i>in vitro</i> monitoring	a
* invertebrate community structure	D

Exposure to pesticides is widespread and can be extensively-monitored. Deep lake basins may provide good sites for sampling total pesticide loads on the environment. Residues in predatory birds and fish are sensitive indicators of exposure and may provide early detection of pesticide problems.

Biological responses, however, may be measurable only at relatively high levels of pesticide exposure, which would probably be localized. For example, measures of invertebrate communities would provide a sensitive indicator of response to spill events. For monitoring pesticides in intermittent waters, invertebrates are currently the only available indicator. More research is needed on the effects of pesticides and other toxics on pothole ecosystems.

It would be useful to know what fraction of the pesticide load is contributed by direct application and run-off from farms, and by longer-range aerial transport. Information on pesticide sales provides a general idea of the amounts being applied over a wide region, and the types used. Pesticide-use surveys could be used to more specifically determine details of use in given area.

(See also section on integrated monitoring for the effects of pesticides.)

2. Climate change and variability

<u>STRESSOR and EXPOSURE INDICATORS</u>	<u>Availability</u>
* temperature	A
* precipitation	A
* wind	A
* insolation	A
* drought monitoring	A
water flow and quality	a
<u>RESPONSE INDICATORS</u>	
* soil moisture	a
* distribution of aquatic organisms (presence/ absence data; relative abundance)	D
change in abundance of aquatic organisms	D
loss of wetlands	A
change in water levels	a
change in duration of growing season	A

3. Industrial and municipal discharge

<u>STRESSOR and EXPOSURE INDICATORS</u>	<u>Availability</u>
* quantity of discharge	a
* quality of discharge	a
stormwater discharge	D
compliance	a
water quality (conductivity, salinity, temperature, pH, P, N, coliforms, metals, TSS, BOD, etc.)	a
* toxicity (acute lethality) tests	D
<u>RESPONSE INDICATORS</u> (these would be site-specific)	
biotic community structure	D
fish and wildlife	
mortality	D
sub-lethal effects	D
human health	D

4. Dams and impoundments

<u>STRESSOR and EXPOSURE INDICATORS</u>	<u>Availability</u>
* changes in numbers and kinds	A
* change in procedures for flow regulation	A
change in hydrology	A
destabilization of shorelines:	
physical	a
biological	a
mobilization of mercury	D
* proportion of stream-length impounded	D
* proportion of streams with dams	D
<u>RESPONSE INDICATORS</u>	
* mercury in tissues	a
* change in abundance and distribution of fish and wildlife (e.g., number of carp [D])	a
siltation	a
recreational use	A
change in fish and wildlife habitat	a
change in thermal regime	a

5. Irrigation

<u>STRESSOR and EXPOSURE INDICATORS</u>	<u>Availability</u>
* change in area irrigated	A
* change in quantity of water used:	
groundwater	a
surface water	a
* change in salinity:	
run-off	D
surface soil	D
* water table height	a
run-off volume	a
<u>RESPONSE INDICATORS</u>	
crop yield on irrigated lands	a
* fish, wildlife, and invertebrate communities	D
macrophyte and periphyton communities	D

6. Drainage

STRESSOR and EXPOSURE INDICATORS

Availability

- * area drained
- * flooding (frequency and extent)
- * spring discharge in streams
 - channelization
- number of kilometers of ditches
- change in salinity
- change in turbidity
- bedload transport
- downcutting (streambank erosion)

D

A

A

a

A

A

a

a

a

RESPONSE INDICATORS

- * loss of habitat
- change in fish spawning areas
- change in flood plain
- loss of stability

a

D

D

D

7. Nutrients

STRESSOR and EXPOSURE INDICATORS

Availability

- * concentrations in surface water
- * concentrations in groundwater
- nutrient loading:
 - from fertilizer run-off
 - from waste discharge

A

a

A

D

RESPONSE INDICATORS

- * increase in eutrophication
- change in biotic community structure

a

D

8. Exotic taxa

<u>STRESSOR and EXPOSURE INDICATORS</u>	<u>Availability</u>
* appearance of exotic taxa (see below)	A
* change in distribution of exotic taxa	a
<u>RESPONSE INDICATORS</u>	
* change in community structure	D
loss of commercial sport fishery	a

A partial list of exotic taxa that are potentially important stressors to aquatic ecosystems in the prairie region includes: purple loosestrife, eurasian milfoil, zebra mussel, European carp, black and white crappie, white bass, grass carp, tilapia, rainbow smelt, brook trout, and rainbow trout.

Extensive Indicators of Climate Change in the Prairie Region

Workshop Group 3 identified some candidate indicators suitable for extensive-monitoring of the effects of climate change. These indicators include the following:

Distribution of Lake Trout.

Distribution of *Mysis relicta* (a pelagic crustacean).

Peak-season phytoplankton community.

Distribution of terrestrial plants near a limit of a climatically-determined range (including native species, and deliberately introduced crop species or cultivars). Community composition is a more relevant measure than biomass.

Changes in pattern and intensity of weather-dependent predictions of risk of forest fire.

Depth and distribution of permafrost, depth of thaw of active layer.

Area of wetlands, and of abundance and distribution of dependent biota such as waterfowl, certain plants, etc.

Some cautionary notes about indicator selection were identified. It is recognized that choice of a particular indicator species can be problematic, in part because hypotheses about ecological relationships among species within ecosystems generally have not been verified. For example, *Mysis relicta* was suggested as a useful indicator because it is believed to be potentially sensitive to changes in predation, toxic substances, and climate change. It remains unclear, however, how changes in the distribution or abundance of this species might indicate or warn of other important ecological changes. Participants thus felt that intensive-monitoring programs should have the active involvement of research scientists (as is proposed in the framework document), and not just be comprised of routine, operational monitoring.

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